Nolan, Carson Y.
Improvement Of Tactual Symbols For Blind Children

Drake

FINAL REPORT

Project No. 5-0421

Grant No. OEG-32-27-0000-1012

IMPROVEMENT OF TACTUAL SYMBOLS FOR BLIND CHILDREN

1 June 1964 — 28 February 1969

Carson Y. Nolan and June E. Morris
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1971
Department of Health, Education, and Welfare
U. S. Office of Education
Bureau of Education for the Handicapped

ABSTRACT

The purpose of the project was to gain information with which to improve the quality of tactual maps for the blind. Empirical studies of the pair-comparison type were conducted, using blind students as subjects, to determine discriminable sets of areal, linear, and point symbols made in plastic and to identify discriminable sets of linear and point symbols embossed in paper. After such sets were identified, discriminable plastic symbols of the three types were combined in six pseudomaps which varied through two conditions of spacing between symbols (.090 inch and .150 inch) and through three conditions of relief (all symbols the same height, linear and point symbols higher than areal symbols but the same height, and point symbols higher than linear symbols and linear symbols higher than areal symbols). These maps were used to study how to combine such symbols. Tactual map reading behavior was analyzed using one of the pseudomaps. Overall, it was found that tactual perception, symbol legibility, map design, and map user training are closely interrelated and all play critical roles in a blind person's ability to use tactual maps.

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The research reported herein was performed pursuant to a grant with the Bureau of Education for the Handicapped, U. S. Office of Education, Department of Health, Education, and Welfare. Contractors undertaking such projects under government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official position of the Bureau of Education for the Handicapped.

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FOREWORD

The research project described in this report originally started as a straightforward empirical study of the legibility of tactual symbology. The overall purpose was to improve the quality of tactual maps by this means. As the authors progressed toward this goal, it became painfully obvious that this tactic was limited in potential effectiveness. It became clear that the tactual map problem transcends the problem of symbol, legibility, being firmly wedded to problems in tactual perception, map design, and map user training. Consequently, later research effort was diverted into a study of map design and a study of map user behavior.

The initial five symbol studies were originally written as research articles as the research progressed. Subsequently, it was decided to cast all the material into a single report which would be oriented heuristically in order to formulate ideas upon which to design a much broader program of research in the tactual map area. It is for this reason that the review of literature contains many articles that post-date much of the research and that the final chapters diverge into quite broad perspectives.

The authors wish to express their appreciation to the supervisors and staffs of the Alabama, Florida, Kentucky, Illinois, Indiana, Ohio, and Western Pennsylvania schools for the blind and to those of the city schools of Cleveland, Columbus, and Parma, Ohio; and Atlanta, Georgia for their very great cooperation and assistance. To the visually handicapped pupils of these schools who served as subjects, the authors are deeply indebted.

Karen Fieg helped collect data for chapter four and Cleves Kederis contributed similarly for chapter eight. Both assisted in data analysis.

Edward Berla' contributed constructive commentary to the report. Judy Riley typed the manuscript.

All the above are responsible for the quality of the report, but are in no way responsible for its failings.

Carson Y. Nolan

June E. Morris

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CHAPTER ONE

DESCRIPTION OF THE PROBLEM

In the education of blind children, there is a continuous need for a variety of tactile nonverbal graphic displays. These displays take the form of maps, graphs, and charts. They appear primarily in books, and are also found in larger sizes for desk top or wall display. Maps constitute the largest and most generalized need for tactual nonverbal displays.

Sherman, one of the first geographers and cartographers to become interested in maps for the blind, has described this need. He states (1965), "most of the common, thematic maps, standard equipment in the sighted classrooms, have never been produced in a form blind persons can read by touch. Yet the need of blind people is as great, if not greater at times, than the need of the sighted individual [p. 130]." Sherman adds, "I have never yet seen a thematic map of world or national population distribution prepared for the blind, nor a map of vegetation, agricultural activities, manufacturing regions, or any of the special-purpose maps we take for granted and expect in a school atlas [p. 132]." Although this somewhat overstates the need, since many such maps have been produced on paper in atlas form by the American Printing House for the Blind (APH) in the last decade, the low legibility of embossed paper maps still leaves the problem paramount.

Tactual maps appear in a variety of forms and media. Paper maps can be embossed or have images imposed through Virkotype printing or silk screening. Desk and wall maps are often carved and/or built up of wood. Many such maps can be dissected. Such wooden maps serve as master from which maps are molded in paper-mache, plastic, or rubber. A variety of masters is used to produce maps in vacuum formed plastic.

Regardless of the medium used, many problems confront the tactual map producer. Consistently in the past, some of these problems have stemmed from lack of availability of the broad range of information and skills required for adequate map design. For example, "The first record in this country of a professional cartographer involved in graphics for the blind dates back only to 1958 [p. 80]" (Wiedel, 1969). In a subsequent discussion of the problem of skills in map development, Wiedel points out that geographers working in the area lack knowledge of tactual perception and appropriate evaluation procedures while psychologist working on the problem lack knowledge of cartography and the graphic arts. This comment gains significantly in pregnance when it is considered that most of those most directly involved in design and manufacture of maps for the blind lack knowledge and skill in both of these fields.

Of the many difficulties confronting the map designer, lack of knowledge of general laws governing tactual perception and their implications for design of tactual symbology is particularly critical. Among the problems here are that pictorial symbolization is rarely possible

tactually, that many visually different symbols cannot be discriminated tactually, and that symbol rotation may confuse the reader. When the task of combining symbols into meaningful wholes is attempted, the affects of lack of perceptual knowledge are compounded.

These deficits complicate decisions even on appropriate size of maps. As Wiedel states, "Size of a plan or map is an important factor, since the blind can read an area only as large as their finger tips. This also places a constraint on the scale and level of detail that can be shown on a plan. Visually we observe the whole, then consider the detail of the parts. The tactual reader, on the other hand, observes the parts and constructs a whole. For the blind to read a page-size map, has been likened to a sighted person reading a large wall map from a normal reading distance of about ten inches [p. 85]."

A great deal of research on a broad scale will be required to resolve the perceptual problems involved in map design. The research described in this report deals only with one small facet of the problem, symbol legibility. As such, it is a sequel to previous research reported by the authors (Morris, 1960; Morris & Nolan, 1961; Nolan & Morris, 1961, 1963).

The initial purpose of this project was fourfold. The objectives were:

(1) To increase the number of discriminable symbols for areas, points, and lines that can be reproduced in vacuum formed plastic. Chapter three describes this study.

(2) To establish minimum discriminable sizes for vacuum formed point symbols. This study is described in chapter four.

(3) To evaluate the discriminability of the symbols now used in embossed paper maps and to increase the number of symbols available for this purpose. These studies can be found in chapters five and six.

(4) To investigate how tactual symbols for areas, points, and lines can best be combined to provide for maximum legibility. A study for this purpose is reported in chapter seven.

The grant was extended to explore two additional goals. These were:

(5) An exploratory study of the behavior of blind students attempting to use "pseudomaps" created as stimulus materials for objective (4) above. Chapter eight contains this study.

(6) Development and evolution of a pilot training program for more adequate map reading behavior. Because of problems discussed in chapter nine, this part of the project was not attempted.

CHAPTER TWO

REVIEW OF RELEVANT RESEARCH

Tactual Acuity

Little study has been made of problems of tactile acuity, especially with reference to the fingertips, a principal sensory organ of the blind. Indeed, the great discrepancies between the sensitivity of the organs of touch and other senses such as the eye and ear do not seem apparent to many persons who deal with the blind. In a recent publication by the National Academy of Science (1968) the following comparison was made. "The contrast between about a million nerve fibres from the eye to the brain and some 40,000 from the ear to the brain emphasizes the relative disdavantage of the ear, while a comparison of the 525-line visual video-image with the perhaps six-line resolution of the fingertip stresses the inadequacy of touch relative to vision [p. 1]."

Research on dimensions of tactual acuity is sparse. During the nineteenth century, psychologists in Germany and other parts of Europe spent considerable effort in study of the two point limen for touch. This threshold, for the fingertip, was found to be 2.3 millimeters or .090 inch for static touch (Boring, 1942, p. 485). With active touch and learning this threshold could be reduced substantially. The findings of these early psychologists for static touch have recently been reaffirmed by Weinstein (1968).

In practical usage, two point discrimination does not appear this acute. Research on braille reading has demonstrated that reducing the interdot distance within the braille cell from .090 to .080 inch significantly reduces reading speed (Calvin & Clark, 1958; Meyers, Ethington, & Ashcroft, 1958). In addition, Nolan and Kederis (1969, p. 63) have demonstrated that braille characters with dots widely spaced are recognized more quickly than those whose dots are all separated by the standard distance (.090).

Unpublished research results (Meyers, 1955) show that blind braille readers can discriminate differences in braille dot height as small as .001 inch with 68% accuracy. Accuracy becomes near 100% when the height between adjacent dots differs by .005 inch. These findings are independent of the tip radius of the braille dot. Solomon (1959) replicated this research with sighted subjects and obtained similar results.

Legibility of Tactual Symbology

Maps and other graphics require three classes of symbology. Areal symbols are used to differentiate areas, linear symbols to identify boundaries or to connect points, and point symbols are used to identify locations. In print maps these symbols can vary along the dimensions of form, size, and color. While legible symbology has long been a problem for tactual maps,

it is only within the last 15 years that it has become a subject for formal study.

The pioneer study was made by Heath (1958) as a doctoral project in the Department of Geography at the University of Washington. He compared the relative legibility of 40 tactual areal symbols reproduced as squares two inches on a side. Heath's study is also original in that it represented the first application of the Virkotype or Gestetner printing processes to maps for the blind. Virkotype printing involves dusting the wet ink-print image with a fine resinous powder. The powder adheres to the ink and when the sheet is heated a plastic-like solid raised image of the printed figure results.

Heath used the method of constant stimulus differences to compare legibility of his symbols when they were randomly grouped in sets of 10. While this approach enabled him to demonstrate differences in legibility among symbols and to identify highly legible symbols within sets, it did not allow for any general statements of relative legibility among the total of 40 stimuli. In a second part of his study Heath showed that the most legible tactual symbols retained their legibility when reduced to squares measuring one-half inch per side.

Following this lead, Morris and Nolan (1961) tested the relative legibility of 12 areal symbols reproduced in Virkotype. Some of these were those used by Heath and others were selected for apparent differences from these. These areal patterns are pictured in Figure 2-1. Using a pair-comparison technique, they defined a legible symbol as one not confused with any other pattern or itself more than 10% of the time. Subjects were braille readers enrolled in grades 4-12. The eight patterns that met these criteria are identified by an asterisk in Figure 2-1. Ability to discriminate these patterns was not related to sex, grade, or chronological age but did appear to have a slight positive relation to mental ability.

Comparison of the legible patterns in Figure 2-1 gives some hint of the variables that appear to contribute to discriminability. Among these are continuous x interrupted, regular x irregular, density of the pattern, and size of the figures making up the pattern.

Additional experience (to be reported later) with the Virkotype medium indicated that the degree of relief (.0045 inch) was inadequate for good legibility, that control of quality was poor, and that humid environments caused rapid deterioration of the medium. Consequently, in 1963 Nolan and Morris replicated the research on areal symbols using vacuum formed plastic as a medium. To produce these symbols, the patterns to be studied were first reproduced in zinc through the photoengraving process. A mold was made by pressing these patterns into soft plaster which was then allowed to harden. Plastic, .008 inch thick, was then drawn into the molds through vacuum forming. The result was patterns embossed to a height of from .018 to .025 inch.

This research was carried out as before except that the symbols studied included the eight symbols previously identified as legible plus five more which appeared to have high potential in this respect. These symbols are pictured in Figure 2-2. Seven symbols of this set met the criterion for legibility as previously described and are marked with an asterisk in Figure 2-2.

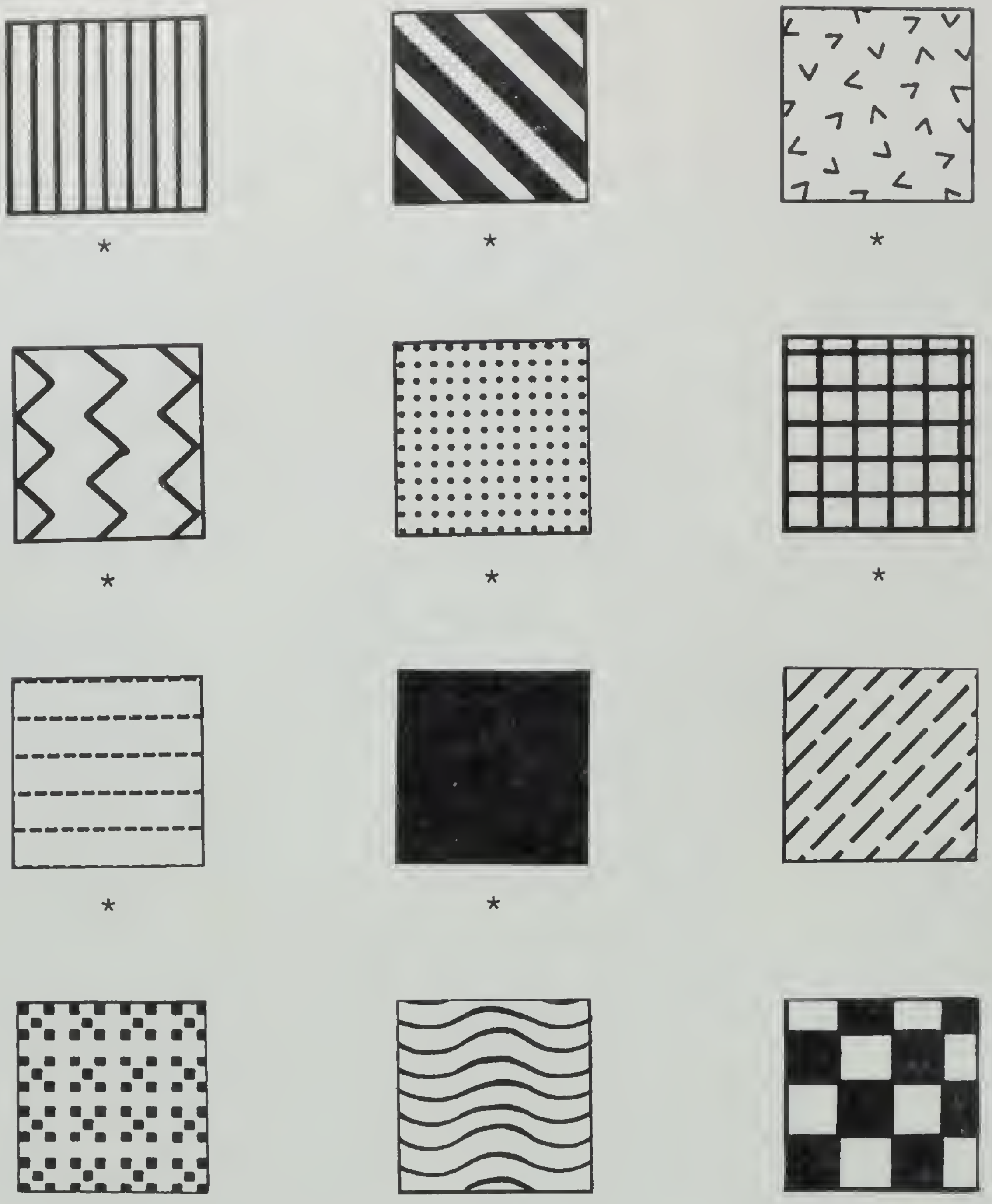

Fig. 2-1. The outside dimensions of the 12 Virkotype areal symbols portrayed are one half the size of those used in the study. The dimensions of the patterns themselves are not altered. Asterisks identify a highly legible set.

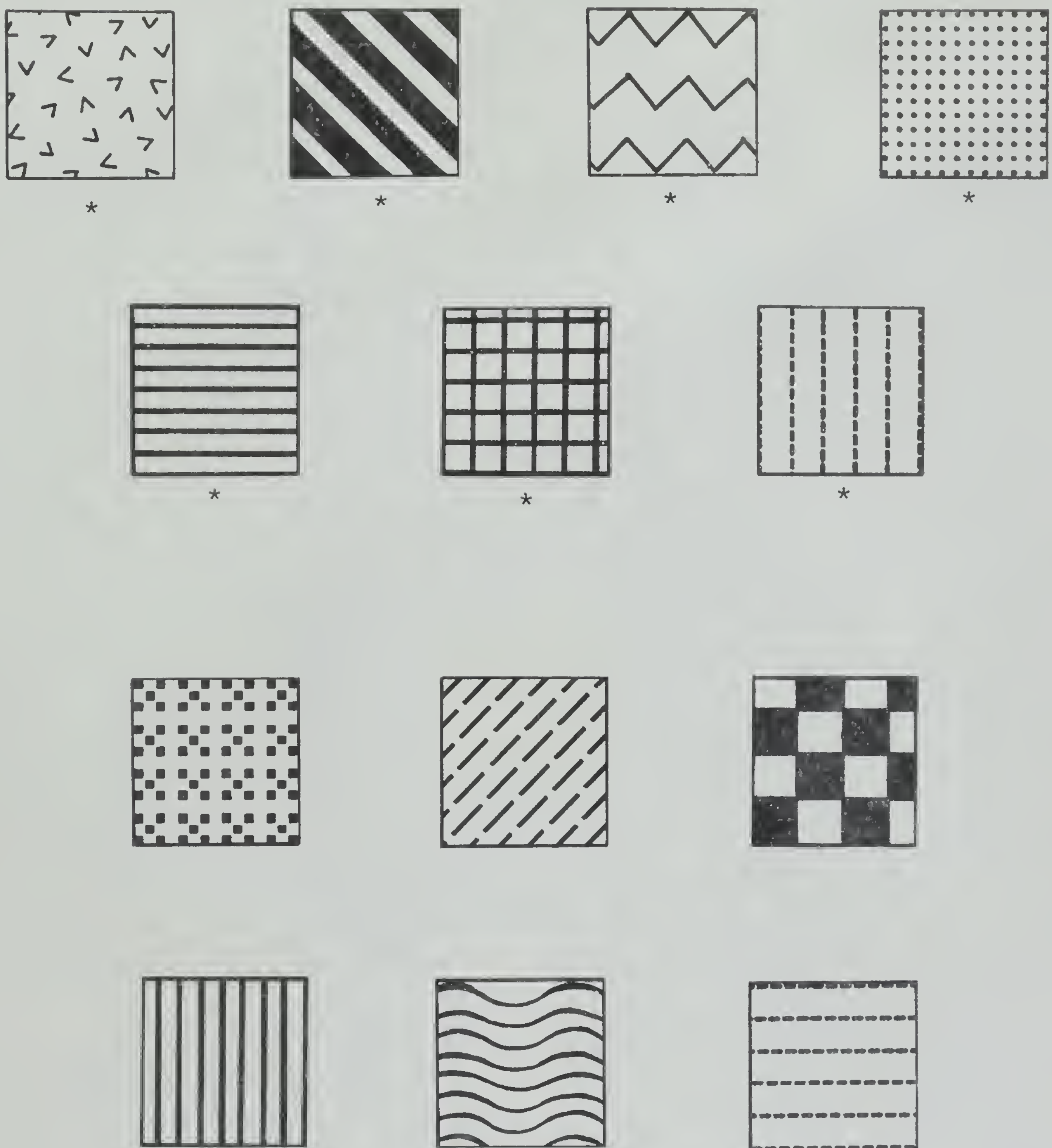

Fig. 2-2. The outside dimensions of the 13 plastic areal symbols portrayed are one half the size of those used in the study. The dimensions of the patterns themselves are not altered. Asterisks identify a highly legible set.

In a subsequent study, Morris and Nolan (1963) undertook to establish the minimum sizes at which these areal symbols would retain legibility. The task in this study required braille readers in grades 4-12 to inspect a stimulus figure mounted on a card and then pick out a similar tactual pattern from among the seven response figures on the card. Stimulus figures were always two inches square, while response figures varied from two inches to one-fourth inch square in steps of one-quarter inch. The results showed that these seven tactual patterns, highly discriminable (less than 10% error) when presented in two inch squares, began to lose discriminability when side length was reduced to one and one-half inches. Only two symbols remained legible when side length reached one-fourth inch. Generally, overall legibility held up well until side length dropped below three-quarters of an inch. Students in the upper grades could discriminate among the smaller symbols significantly better than those in the lower grades. Interrupted-regular patterns appeared most likely to retain legibility when reduced to small size. These patterns were formed of small dots and thin parallel lines.

Schiff (1966) has reported a variety of research aimed at discovering means whereby volunteer workers can produce masters for tactile graphics accompanying recorded textbooks. The masters were produced in aluminum foil or built up using a variety of media and then copied through the vacuum forming process. In one such study, Schiff reported that four grades of sandpaper could readily be discriminated by high school and college level blind students. These papers included Garnet cabinet paper 36-D2 085, Holland flint paper #3, Garnet cabinet paper D wt., LS 480 closed coat, and Garnet cabinet paper C wt., LN 3 100 closed coat. When used as areal symbols, these four papers are distinguishable from one another when vacuum formed in areas as small as three-quarters of an inch square. In addition, Schiff has studied discriminability of area symbols reproduced by a variety of embossing tools. Of most interest in this latter research are some of the dimensions of tactual texture tentatively identified. <u>Intensity</u> of tactual stimulations (sharpness) appeared particularly important as were intensity variations or quality of intensity. <u>Density</u> of texture elements was helpful within narrow limits in facilitating discriminability. Of considerable less use were cues arising from differently <u>shaped</u> texture elements or differently <u>oriented</u> texture elements (lines).

Nolan and Morris (1963) also undertook the study of linear and point symbols. Their first effort used symbols reproduced in the Virkotype medium and compared legibility of sets of 18 symbols each. Pair-comparison methods were used; braille readers in grades 4-12 served as subjects; and a 10% criterion was established as before. The problems with this medium previously reported were even more critical for these smaller figures and, as previously indicated, research using this medium was abandoned.

This research was repeated using vacuum formed plastic as a medium. Symbols pictured in Figure 2-3 were compared when embossed to a height of .018-.025 inches. Among the 13 linear symbols, those marked with an asterisk were found to meet the criterion for discriminability.

Dimensions which seem to differentiate linear symbols appear to be continuous-interrupted, thick-thin, smooth edge-ragged edge, and single-double. For interrupted figures, imposed rhythm also seems a factor.

Research on 14 vacuum formed point symbols identified eight patterns meeting the criterion. These are marked with an asterisk in Figure 2-4. Dimensions contributing to legibility for these figures include form, size, solid-open, and continuous or punctate. Corners of small figures appear to play a significant role in legibility.

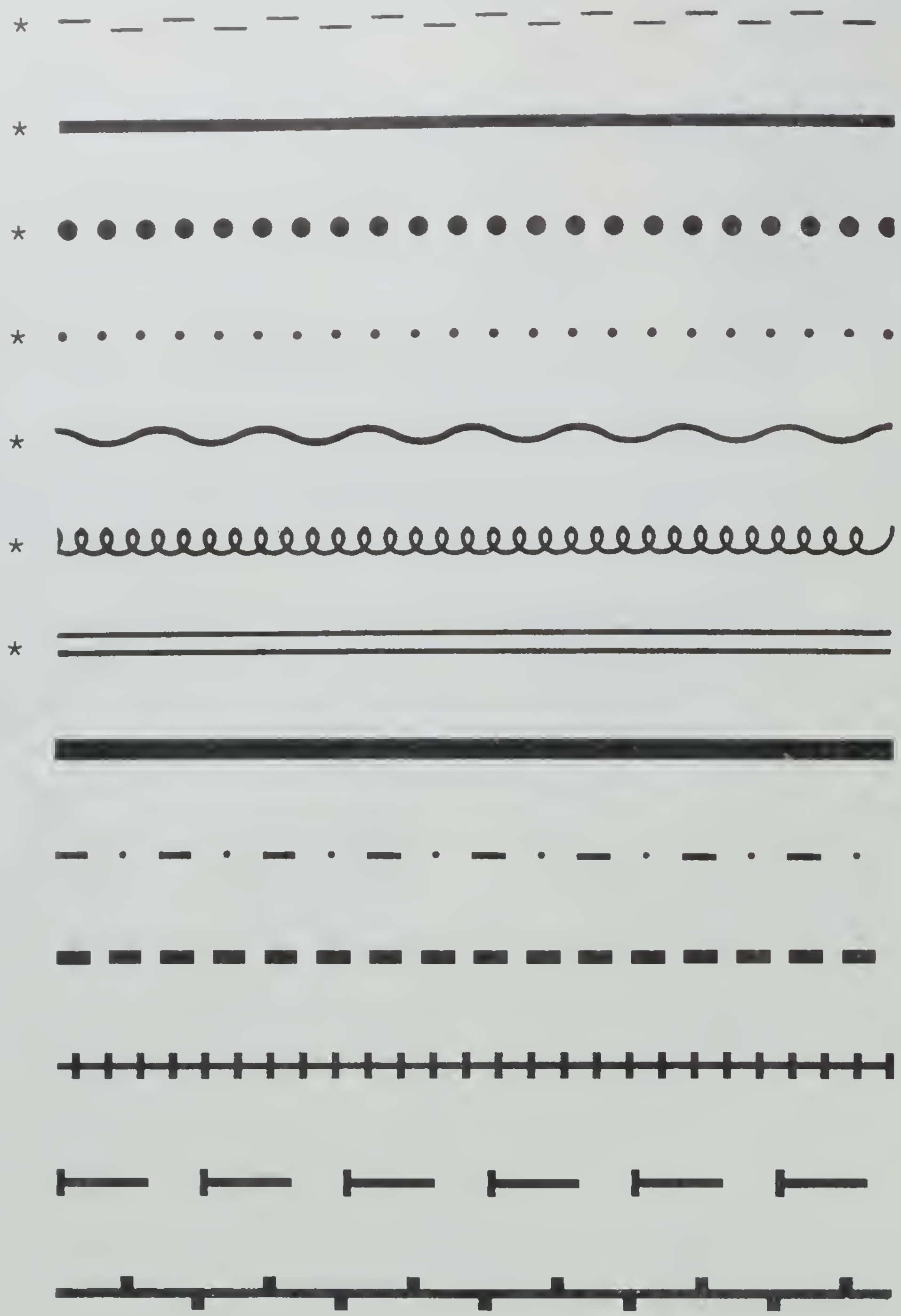

Fig. 2-3. The 13 plastic linear symbols portrayed are the actual size used in the study. Asterisks identify a highly legible set.

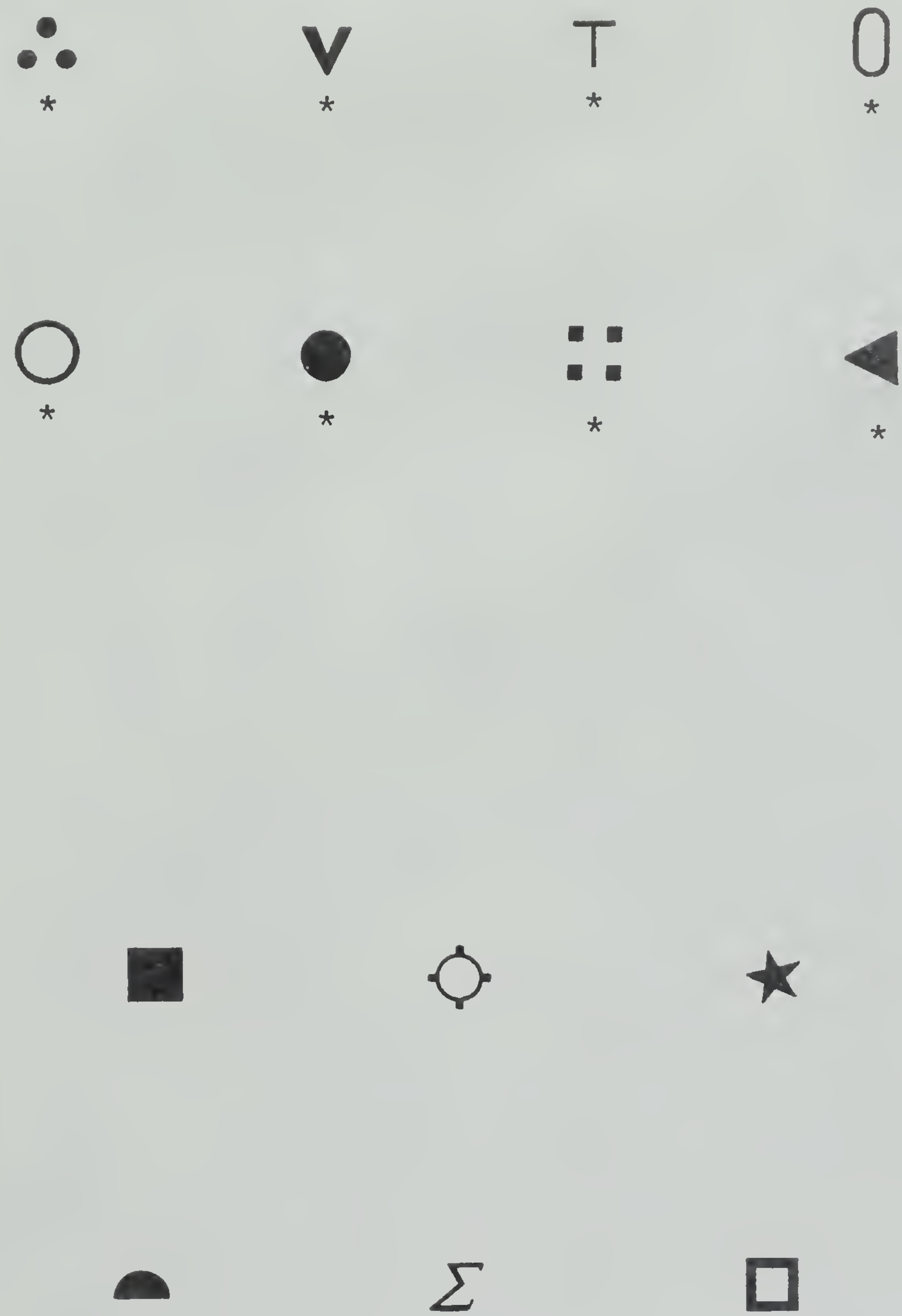

Fig. 2-4. The 14 plastic point symbols portrayed are the actual size used in the study. Asterisks identify a highly legible set.

In 1966, Schiff, Kaufer, and Mosak described efforts to develop a linear symbol having structural properties which would convey "differential direction" and which would lead to quick tactual recognition of the information symbolized. In designing his "tactual arrow" Schiff attempted to "capitalize on any stimulus characteristics which might aid in conveying the concept for which the symbol will stand." He achieved this end by developing a tool that embossed a symbol resembling the teeth on a saw with the edges slightly smoothed. This symbol when scanned with the fingertips in one direction (forward) felt smooth and when scanned in the opposite direction felt sharp (backward). Eighty percent of blind subjects tested expressed preference for this symbol over an embossed "visual arrow." Some instruction on use of this symbol was found necessary. These findings emphasize the rhythmic factor in symbol differention mentioned above. In 1966, Schiff also reported research on identifying tools which would enable volunteers to emboss lines on aluminum foil masters for tactual diagrams. Ten tools which would produce discriminable lines were identified or especially developed.

The legibility of embossed upper-case letters of the English alphabet for use as tactile point symbols was studied by Schiff (1966). These letters reproduced in vacuum formed plastic were nine-sixteenths inch high with a stroke width of one-sixteenth inch. Both blind and sighted high school and college students served as subjects. With the exception of the nine letters D, G, Q, K, M, N, V, W, X, these forms had high potential for symbolic tactual use. Many blind students were already familiar with letter shapes.

In related research, Schiff compared legibility of letters with a rough surface embossed on a smooth background with identical letters where the surface variables were reversed. Although results failed to reach statistical significance, rough letters on a smooth surface resulted in somewhat faster response times and fewer errors for blind students.

Foulke and Morris (1961) and Nolan and Morris (1963) used paired-associates learning techniques to demonstrate that braille students could learn easily to associate names with the sets of highly legible areal, linear, and point patterns identified in their studies.

Punctate forms, as exemplified by the braille cell, present a special case of point symbols. Some characteristics affecting the legibility of these have been identified in previous research. Interdot separation seems to be optimum near .090 inch and research indicates that reduction of this distance increases symbol recognition time (Meyers, Ethington, & Ashcroft, 1958). The time to recognize such characters is positively related to the number of dots of which they are composed and negatively related to the density of dots within the pattern (Nolan & Kederis, 1969). The legibility of punctate figures was found to be related to their complexity by Foulke and Warm (1967). Efficiency of recognition of such figures dropped markedly when matrices for such figures exceeded 4 x 4.

The inadequacy of orientation of tactile figures as a cue for discriminability has been mentioned by Schiff (1966). The authors have also noticed this deficiency particularly among elementary level students. This inadequacy has been documented in a study by Pick, Klein, and Pick (1966). These researchers presented blind and sighted students with pairs of nonsense forms in which one member of each pair was an upside-down reversal of the other. The subjects were to indicate which member of each pair was upside-down. "The results, in summary, show strong visual orientation identifications by normally sighted subjects which are consistent across the age range sampled. There are no such tactual orientation identifications shown by either normally sighted subjects or totally blind subjects. However, blind subjects who have at least some residual sight do show tactual orientation identifications which are striking in their correspondence with the visual orientation identifications of normally sighted subjects."

Perception of Nonverbal Tactual Graphics

The earliest research in this area explored blind children's ability to recognize embossed pictures of common objects, i.e., cup, chair, hat, house, apple, etc. These pictures were reproduced by means of an ordinary dressmaker's tracing wheel. Picture size was about 5 x 5 inches. In an initial study involving visually impaired children ranging from 6-13 years of age, Merry (1930) found that these students had limited ability to recognize such pictures tactually. This was attributed to lack of familiarity with objects and failure to comprehend the principles of perspective in pictures of tri-dimensional figures. Ability did not appear related to chronological age or mental age. In subsequent study (Merry, 1932), visually impaired students in grades K-12 were required to identify tactually five bi-dimensional designs and 10 embossed figures of tri-dimensional objects. Viewing time was one minute. Recognition of bi-dimensional designs was good with 34% of the students receiving a perfect score. For tri-dimensional objects performance was quite poor with 16% of the group receiving zero scores and a median score of approximately 12% success. Recognition ability was not related to chronological age, mental age, or age of blinding. In a final study, (Merry & Merry, 1933), visually impaired children in grades K-6 were given one or more months training in comparing objects to their two and three dimensional embossed representations. Instruction in designs representing plane figures resulted in improvement for most children ranging from 0-95% with a median of 20%.

Research in this area was dormant until 1966 when Schiff and Isikow described a very interesting study of stimulus redundancy in the tactile perception of histograms. Forty severely visually impaired high school students volunteered as subjects. Students were required to read histograms that varied in difficulty and redundancy. Difficulty was varied in two dimensions--in one case by using bars with relatively large, medium, or small differences in length and in the other by presenting bars of different length in regular or stepwise sequences or in irregular sequences.

Redundancy was varied among the modes of presentation. The modes included (1) bars represented by simple embossed outlines, (2) bars represented by differing grades of sandpaper, (3) bars represented by differing heights of embossage, (4) bars composed of outlines and textures, and (5) bars represented by differing heights of embossage and texture. Mode one had the least redundancy with bar length inseparable from bar outline and mode five had the most redundancy with bar length being associated with coarse texture and greater rise above the diagram surface. All diagrams were reproduced in vacuum formed plastic. The task was to identify the bars with respect to length starting with the shortest. Time and error scores served as criteria. All variables except mode of presentation and stimulus redundancy had significant effects on response time. Mode of presentation and redundancy interacted significantly with difficulty on the error measures. When size differences among bars were small, the most redundant presentation produced fewer errors. When size differences were medium or large, the less redundant modes were equally legible. Interestingly enough, bar length differences of medium length (proportionality 10%) provided for greatest legibility. However, lack of control of orders of presentation in this experiment raise some question about these conclusions.

Schiff (1966) has outlined some general principles of tactual perception which apply to tactual drawings. These can be summarized as follows:

1. <u>Outline shape</u> of small figures is not a very good code for the tactile senses. Discrimination of such shapes is slow and inaccurate, particularly for figures of less than one-half inch in diameter or when smaller figures are used to form tactual patterns.

2. <u>Direction of lines</u> is a poor tactual code for areal figures unless care is taken to scan the figure with the fingers in several different directions. Under these circumstances direction can be a good code.

3. <u>Height of a tactual edge</u> is an excellent cue for discrimination. Patterns providing for differential rates of digital skin deformations provide an excellent basis for tactual discrimination. Important variables here appear to be rate of deformation and amount of deformation.

4. <u>Compatibility of structure</u> in that the structure of a tactile symbol suggests the information to be communicated is important, e.g., parallel lines suggest a railroad track.

5. <u>Contrast</u> is a basic principal in that in a complex graphic the symbols for areas, points, and lines should be different along as many tactual dimensions as possible. Visual contrast is not a good index of tactual contrast.

6. <u>Simplicity</u> is the second most important principle after contrast. The best diagram is usually the most simple.

CHAPTER THREE

INCREASING THE NUMBER OF LEGIBLE PLASTIC AREAL AND LINEAR SYMBOLS

In previous research, Nolan and Morris (1963) identified highly legible sets of seven areal symbols and seven linear symbols that had been reproduced in the plastic medium. The present study represents an effort to increase the number of symbols within each set.

Method

Subjects

Sixty legally blind students who traditionally read braille and who were assigned to regular classes served as subjects. Twenty each were from grades 4-6, grades 7-9, and grades 10-12. These included 26 males and 34 females, 46 of whom were enrolled at the Alabama Institute for the Deaf and the Blind at Talladega and 14 of whom were enrolled at the Indiana School for the Blind at Indianapolis. Those with sufficient residual vision to see the items were blindfolded. This was ascertained by each subject's own report as to whether he could see the sample items. The same subjects participated in evaluation of both areal and linear symbols. Table 3-1 describes the subjects. As previous research (Morris & Nolan, 1961; Nolan & Morris, 1963) had found no difference in ability of the sexes to make tactual discriminations, no effort was made to equate the groups by sex.

Three grades at each level provided the 20 required subjects. Seven were used from two of the three grades and six from the third with the latter being determined randomly.

At the Alabama school, all students who were available participated. Subsequently, one student was randomly selected to be omitted, there being one too many from his grade. All subjects from the Indiana school were chosen randomly in numbers sufficient to complete the number required for each grade.

TABLE 3-1

Number and Sex of Subjects from Each Grade

	Males		Females			
Grade	Alabama	Indiana	Alabama	Indiana	Grade Total	Level Total
4	3	0	4	0	7	
5	4	1	0	1	6	20
6	4	0	2	1	7	
7	2	1	3	1	7	
8	1	0	4	2	7	20
9	2	1	2	1	6	
10	1	2	4	0	7	
11	3	0	4	0	7	20
12	0	1	3	2	6	
Total	20	6	26	8	60	

Experimental Materials and Design

Symbol selection or design was guided by earlier findings concerning dimensions along which symbols seemed to vary. For areal symbols, these were continuous x interrupted, regular x irregular, density of the pattern, and size of the figures making up the pattern. For linear symbols, these were continuous-interrupted, thick-thin, smooth edge-ragged edge, and single-double. For interrupted lines, rhythm may also be a factor. For lack of further data of what constituted tactual discriminability, apparent visual legibility was also used as criterion.

Areal and linear symbols were reproduced in plastic by means of the vacuum forming process. Areal symbols were made up in two inch squares and linear ones in segments four inches long. Eleven areal and 13 linear symbols were under study. They can be seen in figures 3-1 and 3-2. The two types were evaluated separately.

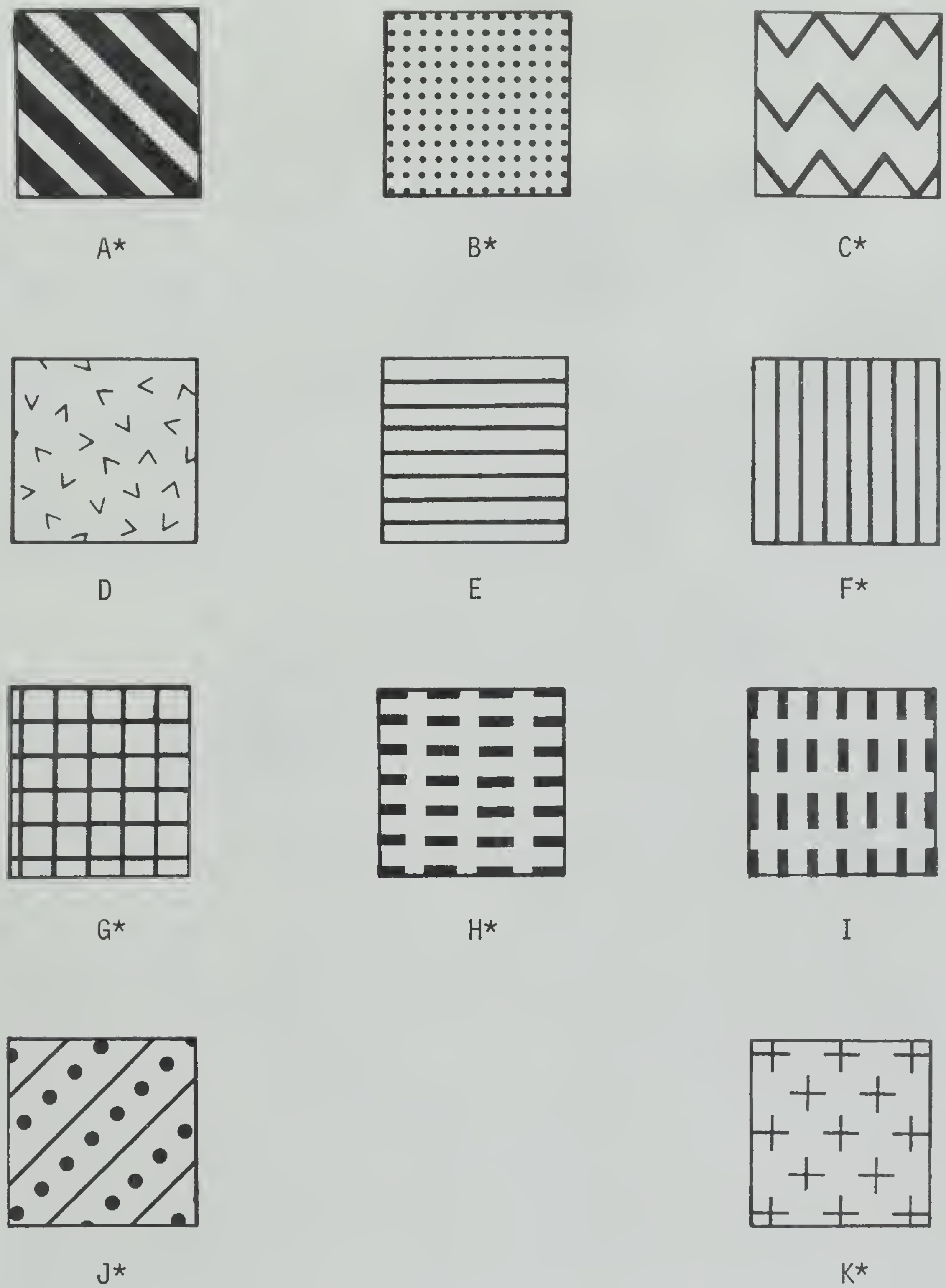

Fig. 3-1. The outside dimensions of the 11 plastic areal symbols portrayed are one half the size of those used in the study. The dimensions of the patterns themselves are not altered. Each symbol is identified by a letter which is used in reference to it throughout the chapter. Asterisks identify a highly legible set.

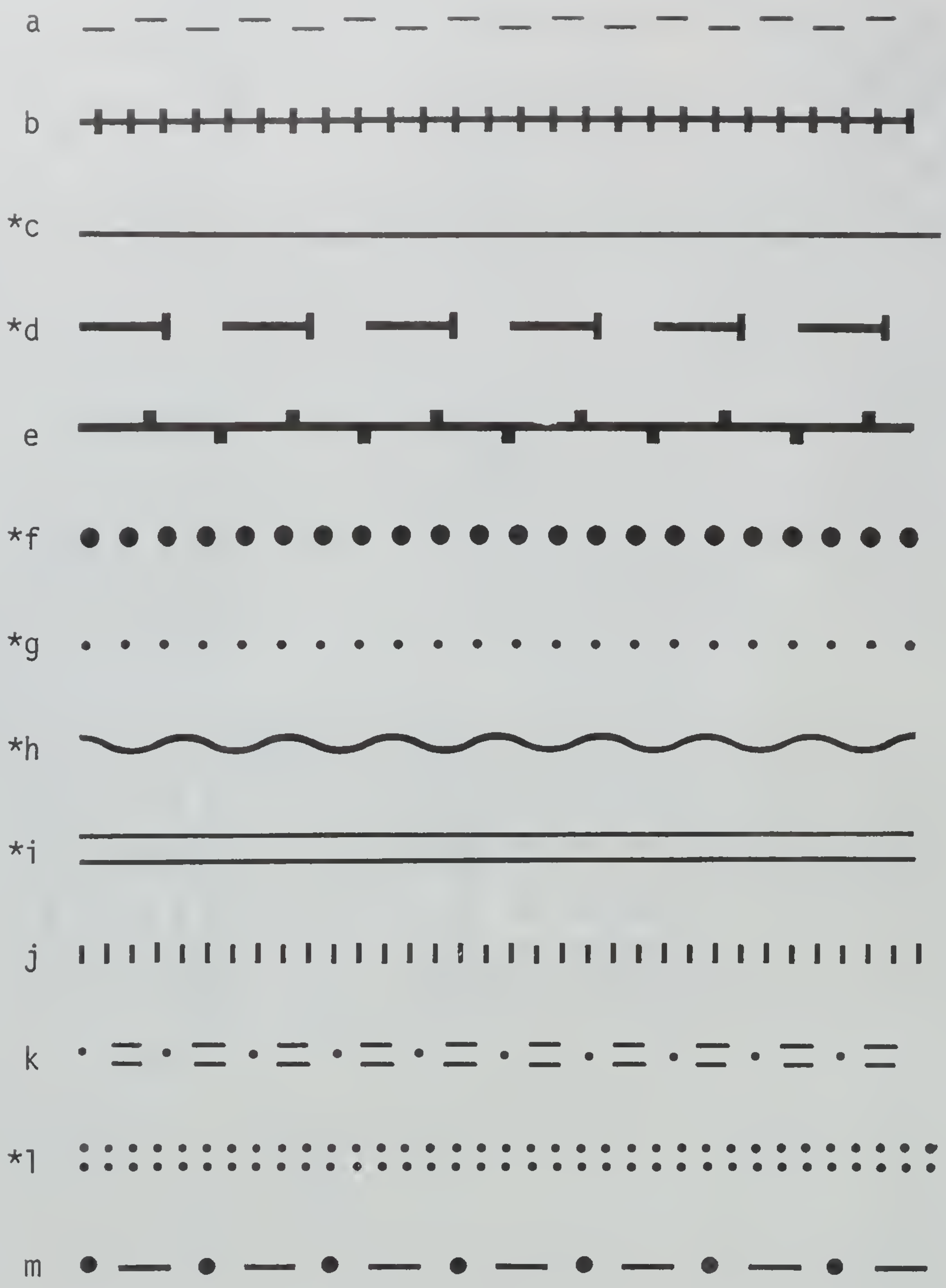

Fig. 3-2. The 13 plastic linear symbols portrayed are the actual size used in the study. Each is identified by a letter which is used in reference to it throughout the chapter. Asterisks identify a highly legible set.

The method of pair comparison was used to determine the discriminability of each symbol. This was accomplished by systematically pairing each symbol with every other symbol of its type (areas with areas and lines with lines) as well as with itself. These pairs were then mounted on 3 x 5 inch cards. Care was taken to keep the directionality constant for those symbols having directionality.

The 11 areal symbols yielded 66 combinations and the 13 linear symbols, 91 combinations. Two sample items, one with like pairs and one with different pairs, were used with each set.

Matrices of the type shown in tables 3-4 and 3-5 were used as guides in constructing the two sets of symbols. First, moving horizontally from left to right and down the matrix, all combinations were randomly assigned an ordinal position within their set. Next, the right/left or up/down position of all different pairs was determined. This was accomplished by randomly assigning the position of the first unlike pair and then, moving as before with the symbol on the y-axis as the reference, alternating its position. This was done to insure each symbol appearing in both positions approximately the same number of times.

Answer sheets for each set were designed to enable the examiner to record a subject's response with one stroke of his pencil.

Procedure

One examiner worked with subjects in Alabama and another with those in Indiana. Directions were read after which subjects were given an opportunity to familiarize themselves with the task by examining the two sample items. When the examiner felt confident that his subject understood what he was to do, he commenced with the sets of symbols. The order in which the sets were presented was alternated so that half of the subjects examined the set of areal symbols first while the other half went through the set of linear symbols first. Subjects were shown the samples preceding the second set to accustom themselves to the different format.

The task for each subject was to examine tactually each pair of symbols and report whether he thought the two members of the pair were alike or different. Time required for the total task was usually about 30 minutes; however, no time limits were imposed.

Criteria

Criteria for a symbol to be considered discriminable were (1) that average confusion with other acceptable symbols should be 5% or less and (2) that confusion with itself or any other single symbol acceptable by criterion (1) should be 10% or less. In addition, for any set of symbols acceptable by criteria (1) and (2), there should be no significant differences in discriminability of acceptable symbols among students in grades ranging from 4 through 12.

Results

Most of the combinations of symbols tested proved to be highly discernible. Reference to tables 3-2 and 3-3 shows that the average subject judged all but two or three pairs in each set correctly. Tables 3-2 and 3-3 describe the performance of subjects at each level as well as for the total group on both sets. It can be seen that at each level, for both sets, one or more subjects judged every pair correctly. No subject from above the sixth grade failed to recognize over four of the pairs of areal symbols and, as revealed by the raw data, only three of the 40 subjects over the sixth grade erred on more than five of the combinations of linear symbols. The majority of subjects at the lowest level recognized most of the combinations as is indicated by the measures of central tendency.

TABLE 3-2

Median Number and Range of Correct Responses, by Grade Level, for 66 Combinations of 11 Plastic Areal Symbols

	Grade			
	4-6	7-9	10-12	Total
Median	63.5	64.8	65.3	64.7
Range	49-66	62-66	62-66	49-66
_N_	20	20	20	60

TABLE 3-3

Median Number and Range of Correct Responses, by Grade Level, for

Combinations of 13 Plastic Linear Symbols

	Grade			
	4-6	7-9	10-12	Total
Median	87.5	88.8	90.0	89.0
Range	79-91	86-91	78-91	78-91
_N_	20	20	20	60

Tables 3-4 and 3-5 are matrices showing the percent of errors made on each combination for the areal and linear symbols, respectively. Only five of the areal combinations were confusing enough to cause over 10% recognition error. Careful scrutiny indicated the best set of areal symbols to be A, B, C, F, G, H, J, and K. These eight symbols meet both criteria (1) and (2) and are identified in Figure 3-1 by an asterisk.

Nine of the combinations of linear symbols were incorrectly identified by over 10% of the subjects. Of these, four were of like pairs which were incorrectly called different. These, in accordance with criterion (2), were eliminated reducing the number of linear symbols to nine. After consideration of the other combinations frequently confused, it was found that the seven symbols, c, d, f, g, h, i, and l best met both criteria (1) and (2). These are identified in Figure 3-2 by an asterisk.

TABLE 3-4

Percent of Error in Discriminating Difference or Likeness in Each of 66 Combinations of 11 Different Plastic Areal Symbols (N=60)

	A	B	C	D	E	F	G	H	I	J	K
A	1.7	0.0	3.3	0.0	1.7	3.3	6.7	0.0	0.0	1.7	0.0
B		0.0	0.0	0.0	16.7	3.3	1.7	3.3	1.7	0.0	0.0
C			6.7	1.7	0.0	0.0	1.7	0.0	0.0	1.7	3.3
D				6.7	0.0	0.0	0.0	0.0	0.0	11.7	33.3
E					1.7	18.3	5.0	0.0	3.3	0.0	0.0
F						5.0	5.0	3.3	5.0	0.0	0.0
G							8.3	3.3	1.7	1.7	0.0
H								5.0	20.0	1.7	0.0
I									5.0	3.3	0.0
J										5.0	5.0
K											5.0

TABLE 3-5

Percent of Error in Discriminating Difference or Likeness in Each of 91 Combinations of 13 Different Plastic Linear Symbols (N=60)

	a	b	c	d	e	f	g	h	i	j	k	l	m
a	15.0	0.0	0.0	1.7	0.0	0.0	11.7	1.7	0.0	0.0	0.0	0.0	28.3
b		13.3	3.3	0.0	10.0	0.0	0.0	5.0	5.0	1.7	0.0	0.0	0.0
c			0.0	0.0	3.3	0.0	0.0	3.3	10.0	0.0	0.0	0.0	0.0
d				3.3	1.7	1.7	0.0	0.0	0.0	1.7	0.0	0.0	11.7
e					20.0	0.0	0.0	8.3	1.7	0.0	0.0	0.0	3.3
f						5.0	6.7	0.0	0.0	1.7	3.3	0.0	6.7
g							5.0	0.0	0.0	0.0	0.0	0.0	3.3
h								3.3	0.0	0.0	0.0	0.0	0.0
i									0.0	0.0	0.0	0.0	0.0
j										11.7	8.3	41.7	0.0
k											1.7	21.7	0.0
l												0.0	0.0
m													5.0

Kruskal-Wallis one-way analyses of variance were run to test for a suspected grade level difference. These were computed separately for the eight areal and seven linear symbols that met criteria (1) and (2). $\underline{H}$ for the areal symbols was found to be 12.33 which indicated a grade level difference in performance significant at the .01 level. For the set of linear symbols, $\underline{H}$ was found to be 4.23, a value too low to be significant at the .05 level. As the same subjects participated in both parts, the grade level difference found with only one of the sets indicates a subtle difference in the difficulty of the two sets of symbols. Reference back to Table 3-2 will show that the upper two levels performed very similarly with the lower level doing less well and less consistently on the set of areal symbols.

Having found a grade level difference, Pearson product-moment coefficients of correlation were run to relate performance with chronological age. Correct scores for the total sets and age in months were the measures used. The resulting $\underline{r}$ for areal symbols was .41 which was significantly different from zero at the .01 level and an $\underline{r}$ of .23 for the linear symbols which was not significantly different from zero at the .05 level. This finding is consistent with the Kurskal-Wallis results.

Discussion

The grade level difference found in recognition of areal symbols appears to be of statistical but not practical importance. The criterion requiring there be no difference in discriminability between grade levels was established to serve as a rationale for a single set of graphic symbols to be used by all tactual readers. Just as the same braille codes (literary, Nemeth, and musical) are used by all English speaking braille readers, it seemed desirable to have a standardized graphic code.

During the seven years tactual symbols have been under study at the American Printing House for the Blind, symbol design and production technique have been continuously improved. As a result, the two sets tested and reported here were so discernible that, after elimination of symbols not meeting criteria (1) and (2), 98% of the areal pairs were correctly identified and 99% of the linear pairs. Table 3-6 shows the percent at each level.

TABLE 3-6

Percent of Areal and Linear Pairs of Symbols Meeting Criteria

(1) and (2) Correctly Judged by Subjects at Each Level

Grades	Areal	Linear
4 - 6	94.9	97.7
7 - 9	98.5	99.1
10 - 12	99.4	99.1
Total	97.6	98.6

With a minimum of 95% of the pairs being recognized by any level, it seems of little practical importance that a grade level difference was found. Just as students' braille skills improve with practice and maturity, it is reasonable to assume their ability to use other forms of tactual symbols also might improve with practice and maturity. In previous evaluations of plastic symbols, grade differences frequently have been observed where data from total sets were used in the analyses; however, these differences disappeared when data from symbols not meeting criteria (1) and (2) were eliminated.

The research endeavor was not successful in substantially increasing the numbers of usable symbols. If the grade level differences found in recognition of the areal symbols are disregarded, the eight areal symbols meeting criteria (1) and (2) are only an increase of one over the set identified previously while the seven discriminable linear symbols identified here are an increase of none over those previously found (Nolan & Morris, 1963). It should be noted, though, the quality of the symbols has been upgraded. These results together with those of previous research strongly suggest that the number of tactually displayed patterns that can be discriminated within sets may be restricted to eight or ten.

Several questions occur as to why greater numbers of discrete symbols, within sets, cannot be identified. First, could it be that there is an inherent limitation in the variety of tactual discriminations a person can make? Second, could it be that there is an inherent limitation in the variety of tactually different configurations possible? And third, what is the cause of self-errors? In the set of areal symbols tested no pair had over 10% self-errors but among the linear symbols, four did. Only those prevented the four from meeting criteria (1) and (2). With them there would have been 11 usable linear symbols; a substantial increase over seven.

Throughout the studies of tactual symbols a disproportionately large number of self-errors have occurred. It was suspected these might be the result of a set for saying different, but the data do not confirm this (Nolan & Morris, 1963). It is known that the proportion of like to different responses are inversely related to the number of symbols being tested and; therefore, the number of pairs in a set. But again, the data do not indicate a significant relationship here. As with the grade differences found with the areal symbols, possibly the self-errors found do not constitute a practical problem. Under experimental conditions, subjects are actively seeing even minute differences between members of pairs. Given a structured set, as in the legend of a map, the user would not be seeking differences as much as likenesses.

These results tend to confirm some of the parameters that distinguish tactual symbols as suggested in chapter two. For area symbols these were continuous-interrupted, regular-irregular, the pattern density, and size of the figures making up the pattern. Directionality of patterns was not found to be a distinguishing characteristic for areal symbols. Both symbols F and H were found to be confused about 20% of the time with their counterparts when rotated 90°. Parameters distinguishing linear symbols appeared to be continous-interrupted, thick-thin, smooth edge-ragged edge, and single-double. An attempt to use rhythm as a distinguishing feature of symbols b, j, k, and m failed to provide evidence that this parameter was significant.

Summary

Eleven tactual areal symbols and 13 tactual linear symbols made in plastic by means of the vacuum forming process were evaluated for discriminability, within types, by the method of pair comparison. Eight of the areal symbols proved discernible, one from the other. Seven of the linear symbols met stringent criteria for discriminability. These results suggest that the number of tactual areal or linear symbols which are discriminable in a set may not exceed eight or ten.

The results generally confirmed the parameters that distinguish tactual symbols. However, the results raised serious questions concerning the distinguishing quality of orientation for areal symbols and rhythm for linear symbols.

CHAPTER FOUR

LEGIBILITY AS RELATED TO SIZE OF PLASTIC POINT SYMBOLS

A major problem in the production and use of graphics for the blind is their large size. Visually man can recognize far smaller objects than he can tactually. Consequently, graphics to be read tactually have to be considerably larger than their visual counterparts. The larger graphics become, the more unwieldy they are to handle and the more expensive they are to make.

The most desirable approach to making tactual graphics appears, first, to determine sets of symbols that are highly legible and then to determine the minimum size at which these symbols retain their legibility. With this information graphics can be made as small as possible while still retaining maximum discriminability. Previous research (Nolan & Morris, 1963) has identified a set of point symbols that meet high standards for tactual discriminiability. The purpose of the study reported here is to explore minimum sizes at which these and additional vacuum formed plastic point symbols can be recognized.

Method

<u>Experimental Material and Design</u>

The discriminability of two sets of 12 tactual point symbols reproduced in plastic by means of the vacuum forming process was investigated. The symbols are shown in Figure 4-1. The only difference between the two sets was symbol size; the smaller symbols being 75% of the size of the ones portrayed in Figure 4-1. The larger symbols were approximately .20 inch on a side while the smaller ones were approximately .15 inch on a side. Since the symbols were drape molded, the limb width was slightly larger than illustrated. The larger symbols portrayed in Figure 4-1 will be referred to as symbols A, B, . . . L and their smaller counterparts as symbols a, b, . . . l.

Eight of the symbols (A, B, D, F, G, H, J, and L) were previously identified as highly discriminable when reproduced in a size slightly larger than those shown in Figure 4-1 (Nolan & Morris, 1963). In the present study symbols A, B, and G were slightly altered as follows: A was made with a flat top rather than a rounded top, the direction of B was rotated 90° counterclockwise, and the four dots making up symbol G were changed from square to round. Symbols A and G were altered so that they could be manufactured by regular production techniques. Symbols C, E, I, and K had not been tested previously.

Selection or design of the additional point symbols was guided by earlier findings concerning dimensions along which symbols seemed to vary. For point symbols, these included form, size, solid-open, and continuous-punctate. For lack of further data of what constitutes tactual discriminability, apparent visual legibility was also used as a criterion.

Fig. 4-1. The 12 plastic point symbols portrayed are the actual size of the larger ones used in the study. Each is identified by a letter which is used in reference to it throughout the chapter. Asterisks identify a highly legible set.

Each of the symbols in each set was systematically paired with every other symbol in its set and with itself. The pairs were mounted on 3 x 5 inch cards with the right or left position of the symbols determined by the flip of a coin. This pair-comparison technique resulted in two sets of 78 combinations each. None of the pairs contained members taken from the different size sets. The two sets were then combined with the ordinal position of the various combinations determined randomly and numbered accordingly. The combined set contained 156 items and was preceded by two sample items composed of symbols not appearing elsewhere in the set.

The symbols themselves were centered on one and one-half inch plastic squares to prevent subjects from being distracted by edges of the background. Symbol relief was approximately .030 inch.

Subjects

Fifty-eight braille readers from the Illinois Braille and Sight-Saving School served as subjects. Twenty were from grades 4-6, 20 from grades 7-9, and 18 from grades 10-12. Previous research (Morris, 1960; Nolan & Morris, 1963) had shown that there is no significant difference between the sexes in their ability to discriminate tactual symbols so no effort was made to equate the sexes. Subjects were randomly selected from the appropriate grade levels after those with useful vision were eliminated.

Procedure

Each subject was seen individually for a period of about 25 minutes. His task was to examine the 156 pairs of symbols and make a decision as to whether the two members of each pair were alike or different. No time limits were imposed. The examiner recorded the subject's response on an answer sheet especially designed for the purpose. Immediately upon giving his response the subject was presented with another card. No information was given as to whether a response was correct or incorrect.

Criteria for acceptance of a symbol as discriminate were those described in chapter three.

Results

Although the subjects who took part in the study were presented with one set of 156 cards containing the set of larger symbols and the set of smaller symbols randomly interspersed, for purposes of analysis the data were categorized by symbol size. The two sets were deliberately presented to the subjects in this manner in order to avoid favoring either size through a possible practice effect.

Table 4-1 gives the medians and ranges of correct scores for both sets of symbols as divided into the three grade groupings. The medians are all high and vary only .8 and .9 between the three grade levels for the larger symbols and smaller symbols, respectively. The ranges indicate that, for each set, one or more subjects from each grade level identified all of the combinations correctly. Because of the cluster of scores on the high end of the possible range, the Kruskal-Wallis one-way analysis of variance by ranks was used to determine whether a difference existed between symbol discrimination and grade level. After being corrected for ties $\underline{H}$ for the larger symbols was .83 and for the smaller symbols was .47. Both fall far short of the 5.99 required for significance at the .05 level indicating no grade differences.

TABLE 4-1

Median Number and Range of Correct Responses, by Grade Level, for Two Sets of 12 Plastic Point Symbols

	Grades 4-6		Grades 7-9		Grades 10-12	
	Larger	Smaller	Larger	Smaller	Larger	Smaller
Median	77.2	75.8	77.3	76.2	76.5	75.3
Range	50-78	34-78	74-78	72-78	65-78	66-78
$\underline{N}$	20		20		18	

Matrices showing the percent of errors made for each combination of symbols are presented in tables 4-2 and 4-3.

TABLE 4-2

Larger Plastic Point Symbols

Percent of Error in Discriminating Difference or Likeness in

Each of 78 Combinations of 12 Plastic Point Symbols (N=58)

	A	B	C	D	E	F	G	H	I	J	K	L
A	5.2	1.7	1.7	1.7	0.0	1.7	0.0	19.0	0.0	3.4	0.0	1.7
B		19.0	0.0	5.2	0.0	1.7	0.0	1.7	0.0	0.0	0.0	6.9
C			8.6	1.7	0.0	0.0	1.7	0.0	0.0	0.0	1.7	3.4
D				5.2	3.4	1.7	0.0	1.7	0.0	0.0	0.0	3.4
E					12.1	1.7	3.4	0.0	1.7	3.4	0.0	0.0
F						10.3	1.7	0.0	0.0	0.0	1.7	0.0
G							6.9	0.0	5.2	0.0	1.7	1.7
H								0.0	1.7	1.7	0.0	0.0
I									0.0	0.0	1.7	0.0
J										3.4	0.0	1.7
K											5.2	1.7
L												5.2

TABLE 4-3

Smaller Plastic Point Symbols

Percent of Error in Discriminating Difference or Likeness in

Each of 78 Combinations of 12 Plastic Point Symbols ($\underline{N}$=58)

	a	b	c	d	e	f	g	h	i	j	k	l
a	5.2	3.4	0.0	3.4	1.7	1.7	0.0	24.1	1.7	1.7	1.7	1.7
b		10.3	0.0	25.9	1.7	0.0	1.7	1.7	0.0	0.0	1.7	24.1
c			3.4	1.7	1.7	0.0	0.0	1.7	1.7	0.0	1.7	1.7
d				17.2	0.0	3.4	1.7	1.7	1.7	3.4	0.0	12.1
e					20.7	5.2	5.2	8.6	1.7	1.7	3.4	1.7
f						20.7	1.7	3.4	1.7	1.7	8.6	3.4
g							8.6	0.0	6.9	1.7	0.0	0.0
h								3.4	0.0	3.4	1.7	3.4
i									0.0	0.0	3.4	1.7
j										10.3	0.0	0.0
k											19.0	1.7
l												5.2

Eight of the larger point symbols (C, D, G, H, I, J, K, and L) and five of the smaller point symbols (c, g, h, i, and l) qualify as highly discriminable in terms of the stipulated criteria In both sets all of the symbols failing to meet criteria except A (a) were dropped because of their self-errors. A (a) was dropped because it was confused with H (h) and inspection of the tables showed H (h) to be more discriminable than A (a). Actually, three other combinations of the smaller symbols were confused over 10% of the time; however, when the symbols with over 10% self-errors were dropped, only the a-h confusion remained. As would be expected, the five smaller symbols comprising the highly discriminable set have their larger counterparts among the eight acceptable larger point symbols.

Inspection of tables 4-2 and 4-3 reveals that when the size of the symbols was reduced the percent of errors made increased for 55% of the combinations, some quite radically. Twenty-eight percent of the combinations showed no difference in the percent of errors made for the two sizes and 17% of the pairs had fewer recognition errors for the smaller symbols though generally these differences were slight.

Discussion

Throughout the pair-comparison studies of tactual symbols, subjects have made proportionally more mistakes recognizing combinations of like symbols than they have in recognizing combinations of different symbols. Reference to Table 4-2 will show that errors greater than 10% occurred in recognizing four of the combinations. Three of the four were for like comparisons. In the set of smaller symbols, Table 4-3, six of the 10 pairs mistaken over 10% of the time were for like combinations. Whatever the cause of errors in identifying symbols as being alike the fact remains that, as many of the like combinations are identified correctly, the ones incorrectly identified are the ones that are less recognizable and; therefore, justifiably excluded from highly discriminable sets.

It was surprising to find no significant grade differences in students' abilities to discriminate as a consequence of reduction of symbol size. Such grade differences, significant at the .01 level of confidence, were reported by Morris and Nolan (1963) in a different type of study which was directed at establishing minimum discriminable sizes (outer dimensions) for a set of seven vacuum formed areal symbols that previously had been identified as highly discriminable when presented in a four-square-inch size. They found that students in grades 8-12 could use symbols with smaller outer dimensions than could students in grades 4-7.

The discussion in chapter three raised the question as to whether there was a limited number of tactual symbols for areas and lines. Earlier findings by the authors (1963) have implied a similar restriction in legible symbols for points which is confirmed by this latest research. The results

of this study point up the strong relationship between symbol legibility and size. Restriction in size reduces the numbers of legible symbols. Similar findings for areal symbols were previously reported (Morris & Nolan, 1963). In addition, the findings suggest that the larger size tested (based on practical considerations of overall size for tactual graphics) may be near optimum.

Summary

In an attempt to establish minimum sizes at which tactual symbols can be recognized, 12 point symbols were reproduced in vacuum formed plastic in two different sizes. Each of the symbols in each set was paired with every other symbol in its set and with itself. The two sets were then randomly interspersed and examined by 58 subjects ranging in grade from 4-12. This pair-comparison technique identified eight of the larger and five of the smaller symbols that met stringent criteria for discriminability. No grade differences were found in the ability of students to discriminate these symbols. Fewer errors were made in judging the larger symbols than the smaller indicating that symbol legibility is related to size and that point symbols should be no smaller than the larger set studied (.20 inch on a side).

CHAPTER FIVE

LEGIBILITY OF POINT SYMBOLS EMBOSSED IN PAPER

Braille is the means by which many blind people encounter the written word. Most braille books are embossed on paper using metal plates and especially adapted flatbed presses. Braille textbooks reflect the variety of subjects found among their print counterparts and require the same varieties of nonverbal graphic materials. Attempts to reproduce these graphs utilize both point and line symbols, but rarely areal symbols.

The tactual symbology used in graphics found in braille books, to a large extent, has been selected for its face validity. No records exist to show it ever has been evaluated empirically. The study reported here describes an empirical evaluation of 19 point symbols currently in use in braille books produced by the American Printing House for the Blind. The purpose of the study was to determine the relative tactual discriminability of the symbols and to learn whether there is a difference in the ability of students from different grade levels to discriminate the symbols.

Method

Subjects

Sixty braille readers in grades 4-12 at the Western Pennsylvania School for Blind Children served as subjects in this study. Twenty were in grades 4-6, 20 in grades 7-9, and 20 in grades 10-12. No effort was made to equate the sexes in the groups as previous research (Morris, 1960; Nolan & Morris, 1963) has shown that there is no difference between the sexes in their ability to discriminate tactual symbols. Students were randomly selected from their grades after those with useful vision were eliminated with six or seven representing each grade. Table 5-1 describes the subjects.

TABLE 5-1

Number and Sex of Subjects from Each Grade

Grade	Males	Females	Grade Total	Level Total
4	3	4	7	
5	3	3	6	20
6	4	3	7	
7	2	5	7	
8	4	3	7	20
9	2	4	6	
10	5	2	7	
11	3	3	6	20
12	4	3	7	
Total	30	30	60	60

Experimental Materials and Design

The 19 point symbols evaluated in this study are shown in Figure 5-1. Each has been assigned a letter by which it will be designated in this report.

As in previous studies, the method of pair comparison was selected as the means for determining the relative tactual discriminability of the point symbols under study. Experimental materials were constructed as previously described.

The task for each subject was to examine the 190 combinations of symbols and judge whether the two symbols making up each pair were alike or different. Because of the large number of pairs, the set was divided into two parts of 95 combinations each. Both parts were preceded by two sample cards containing embossed point symbols other than the 19 under study in order to familiarize the subject with the task. Each subject was seen individually for two periods of about 20 minutes each during which time he examined all 190 combinations, half at each session. Some subjects were presented one of the halves first while others encountered the other half first. Unlimited time was given for the subjects to examine the pairs of symbols and make their judgments which were recorded on an answer sheet by the examiner.

Fig. 5-1. The 19 point symbols embossed in paper that are portrayed here are the actual size used in the study. Each is identified by a letter which is used in reference to it throughout the chapter. Asterisks identify a highly legible set.

Results

The median number of correct discriminations and ranges for the three grade groups are given in Table 5-2. The medians for the groups vary less than one point.

TABLE 5-2

Median Number of Correct Discriminations and Ranges

for 190 Combinations of 19 Point Symbols

	Grades			
	4 - 6	7 - 9	10 - 12	Total
Median	183.5	183.5	184.3	183.9
Range	171-188	179-188	177-188	171-188
_N_	20	20	20	60

The ranges of the three groups show that all students could discriminate most of the combinations of symbols. Out of a total of 190 pairs all recognized between 171 and 188. Due to the recognition scores clustering at the high end of the possible range, an analysis of grade differences was made using the Kruskal-Wallis test. After being corrected for ties, the resulting _H_ was 3.59 which is far below the 5.99 required for significance at the .05 level of confidence. Consequently there was no significant difference in the ability of students at different grade levels to recognize, tactually, point symbols embossed in paper. From a pragmatic point of view this finding justifies use of the symbols under study here in material without regard to grade level of the people who will be using it. The finding that grade differences cause no significant difference in the recognition of tactual symbols is largely consistent with previous research.

Table 5-3 gives the percent of error made in discriminating difference or likeness in each of the 190 combinations of the 19 different symbols. Criteria for acceptance of a symbol were those described in chapter three. Eleven of the symbols studied met those criteria for discriminability and could be retained as a set. These are A, B, C, E, F, I, J, L, M, N, and P.

TABLE 5-3

Percent of Error in Discriminating Difference or Likeness in Each

of 190 Combinations of 19 Point Symbols Embossed in Paper ($\underline{N}$=60)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A	3.3	0.0	0.0	0.0	0.0	5.0	0.0	0.0	1.7	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B		5.0	0.0	0.0	0.0	1.7	38.3	5.0	0.0	0.0	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3
C			6.7	1.7	0.0	0.0	0.0	0.0	0.0	1.7	0.0	1.7	1.7	0.0	0.0	0.0	0.0	3.3	0.0
D				21.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	0.0	1.7	0.0	3.3	1.7	0.0
E					10.0	0.0	0.0	0.0	1.7	8.3	0.0	0.0	1.7	0.0	0.0	0.0	18.3	0.0	23.3
F						6.7	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G							13.3	48.3	26.7	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H								6.7	43.3	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J										6.7	0.0	0.0	1.7	0.0	0.0	0.0	31.7	0.0	0.0
K											10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.3
L												5.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0
M													10.0	0.0	1.7	1.7	10.0	1.7	1.7
N														3.3	5.0	5.0	0.0	16.7	0.0
O															13.3	75.0	0.0	0.0	0.0
P																10.0	0.0	0.0	0.0
Q																	15.0	0.0	0.0
R																		10.0	0.0
S																			6.7

Symbols D, G, O, and Q were eliminated because their self-errors exceeded 10%. Without them, symbols A, C, F, J, L, M, and P were found to be easily discriminated in any combination. After careful deliberation it was decided to retain symbols B, E, I, and N. However, their use necessitated the dropping of symbols H, K, R, and S in order to meet the established criteria. The set of 11 highly discriminable point symbols identified in this study can be used in any combination with one another with great confidence that the users will be able to distinguish them.

Eight symbols from the total set did not meet both criteria and cannot be freely used. The four (D, G, O, and Q) that were dropped because of self-errors should not be used at all. The other four (H, K, R, and S) can be used in certain combinations as is indicated in Table 5-3. For instance, symbol S can be used with symbol R as there were no errors in distinguishing that they were different; however, symbol S should never be used with symbol K as this combination was confused nearly half the time.

It is interesting to note that symbols G, H, and I were frequently not recognized as being different from each other. Apparently the blind have difficulty in differentiating size differences that are not great. This assumption is given further credence by noting the high degree of confusion between symbols O and P.

This is the first study in which a set containing more than eight distinguishable point symbols has been found. This is most probably due to an additional parameter, symbol size, introduced into this study.

The findings of this study have been implemented in map production at the American Printing House.

Summary

Nineteen point symbols embossed in paper were studied to learn (a) which ones were highly discriminable and could be used together as a set and (b) whether grade differences exist in students' ability to use symbols of this type. The 19 symbols were evaluated by means of the pair-comparison method. Each combination of symbols was judged to be either alike or different by 60 blind students; 20 from each of three grade groups.

A set of 11 symbols was identified that met the criteria for high discriminability. No grade differences were found in students' ability to distinguish the symbols under study. The importance of symbol size as a distinguishing parameter for point symbols was emphasized by the results of the study.

CHAPTER SIX

LEGIBILITY OF LINEAR SYMBOLS EMBOSSED IN PAPER

In chapter five, problems of including tactual graphics in braille books were mentioned as well as the lack of empirical evaluation of the relative legibility of the point symbols used. The linear symbols used likewise lack empirical validation. The purpose of this study is to compare 21 linear symbols commonly embossed in paper for relative legibility and for differences in discriminability among children of different grades.

Method

Subjects

A total of 60 legally blind students, all of whom read braille, participated. These students were assigned to regular classes ranging from grades 4 through 12. They are described in Table 6-1. Fifty-eight were enrolled at the Illinois Braille and Sight-Saving School at Jacksonville and two, both fourth grade students, at the Kentucky School for the Blind at Louisville.

Twenty subjects were used from each of the three grade levels; 4-6, 7-9, and 10-12. Seven were chosen from two grades and six from the third grade at each level, the latter grade being selected randomly from among the three grades comprising each level. Subjects from within grades were selected randomly where it was not necessary to use all available students. No effort was made to equate the various groups by sex as previous research (Morris & Nolan, 1961; Nolan & Morris, 1963) had found no difference in the ability of boys and girls to make tactual discriminations.

TABLE 6-1

Number and Sex of Subjects from Each Grade

Grade	Males	Females	Grade Total	Level Total
4	4	3	7	
5	2	4	6	20
6	2	5	7	
7	5	2	7	
8	3	4	7	20
9	4	2	6	
10	3	3	6	
11	3	4	7	20
12	2	5	7	
Total	28	32	60	60

Experimental Materials and Design

The 21 embossed lines under study were systematically paired in 231 combinations in a pair-comparison design; each being paired with each of the other 20 lines as well as itself. The line segments used were four inches long and embossed on the same type of paper as is used in press made braille books and had an average relief of .022 inch. A light coat of shellac was applied to the back of the paper on which the symbols were embossed to enable them to hold up better under use. After the shellac dried, pairs were mounted on 3 x 5 inch cards. The upper or lower position of symbol A was determined randomly by the toss of a coin when paired with symbol B in the initial unlike combination. After that, and throughout the entire set of unlike pairs, i.e., AC, AD, . . ., BC, BD, . . ., TU, the position of the reference symbol (the one bearing the earlier alphabetical position) was systematically alternated to insure approximately the same number of upper and lower positions for each individual symbol. Care was taken to keep the direction constant for all symbols having directionality. Ordinal position of the 231 combinations was determined randomly. The 21 linear symbols studied appear in Figure 6-1.

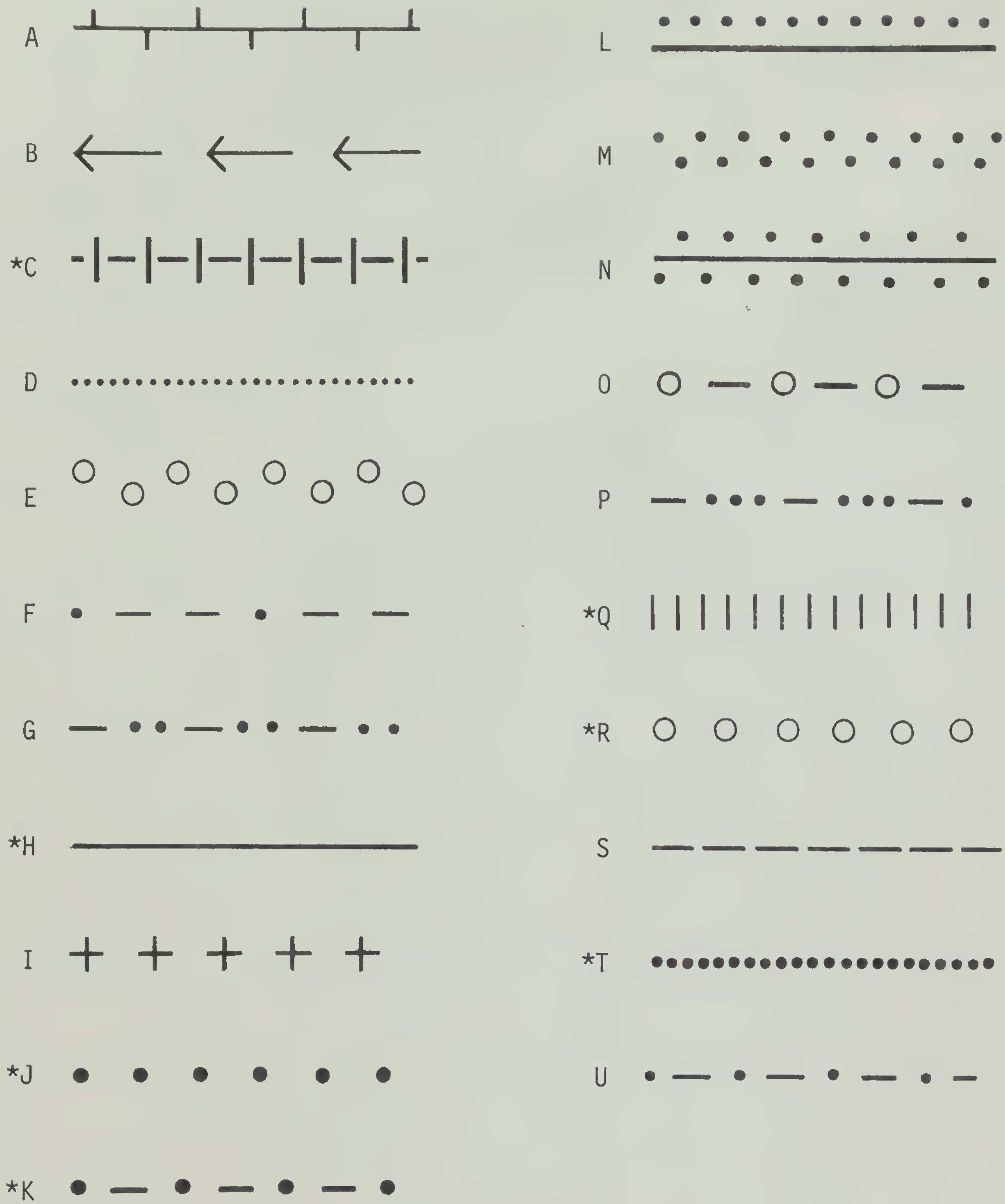

Fig. 6-1. The 21 line symbols embossed in paper that are portrayed here are one half the length of those used in the study. The dimensions of the patterns themselves are not altered. Each symbol is identified by a letter which is used in reference to it throughout the chapter. Asterisks identify a highly legible set.

Procedure

Procedures used followed those described for the previous studies. Most subjects completed the task at one 30-40 minute sitting; however, a few who worked slowly were excused and recalled later to complete the task. As a group, subjects in the lowest grade level took slightly longer than those in the higher two levels.

As in previous studies designed to identify sets of discriminable symbols, criteria for discriminability were (1) that average confusion with other acceptable symbols should be 5% or less and (2) that confusion with itself or any other single symbol acceptable by criterion (1) should be 10% or less. In addition, for any set of symbols acceptable by criteria (1) and (2), there should be no significant differences in discriminability of acceptable symbols among students in grades ranging from 4 through 12.

Results

A summary of performance may be seen in Table 6-2. Shown are the medians and ranges of correct scores obtained at each of the three grade levels and for the entire group for the set of 231 combinations of symbols. Of interest is the finding that the two higher levels exhibited greater variability in their scores than did the lower level while the lower level earned slightly lower median scores than did the upper two levels.

TABLE 6-2

Median Number and Range of Correct Responses, by Grade Level, for 231 Combinations of 21 Linear Symbols

	Grades			
	4 - 6	7 - 9	10 - 12	Total
Median	219.0	224.8	226.2	224.3
Range	204-230	182-230	187-230	182-230
_N_	20	20	20	60

A Pearson product-moment coefficient of correlation was computed to determine the relationship between chronological age and correct score. It was found to be positive but almost negligible with $\underline{r} = .12$. When tested, $\underline{r}$ was found not to be significantly different from zero at the .05 level of confidence, meaning there was no difference in the ability of students to make tactual discriminations of the type required regardless of their age. Subjects included in the study ranged in age from 121 through 242 months.

The primary purpose of the study was to identify a set of linear symbols meeting the specified criteria. Such a set could be used with great certainty that the user could "read" the different symbols comprising the set without confusion. Table 6-3 is a matrix presenting the percent of errors made by subjects on each of the 231 pairs making up the total set.

Only seven of the 21 symbols met both criteria (1) and (2). These were C, H, J, K, Q, R, and T. Six others; A, B, L, M, N, and P; met criterion (1) but had greater than 10% self-errors, and therefore, did not meet criterion (2).

A Kruskal-Wallis one-way analysis of variance was used to test the significance of differences in scores between the three grade levels for just the seven symbols meeting criteria (1) and (2). Prior to making this test all answer sheets were rescored for the 28 items in which symbols C, H, J, K, Q, R, and T were included. The resulting $\underline{H}$ value, after having been corrected for ties, was 3.28 which is below the 5.99 required for significance at the .05 level with 2 $\underline{df}$.

TABLE 6-3

Percent of Error in Discriminating Difference or Likeness in Each of 231 Combinations of 21 Line Symbols Embossed in Paper (N=60)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A	15.0	5.0	3.3	0.0	1.7	1.7	0.0	0.0	0.0	1.7	3.3	0.0	1.7	5.0	1.7	3.3	0.0	3.3	0.0	0.0	0.0
B		11.7	3.3	0.0	3.3	0.0	1.7	0.0	5.0	0.0	3.3	0.0	1.7	1.7	16.7	0.0	0.0	3.3	0.0	0.0	1.7
C			1.7	0.0	1.7	0.0	0.0	0.0	3.3	0.0	0.0	1.7	0.0	1.7	0.0	0.0	1.7	0.0	0.0	0.0	0.0
D				1.7	0.0	0.0	0.0	6.7	1.7	0.0	0.0	0.0	1.7	0.0	1.7	3.3	0.0	0.0	16.7	91.7	1.7
E					8.3	0.0	0.0	0.0	13.3	0.0	0.0	0.0	0.0	0.0	3.3	1.7	1.7	23.3	0.0	0.0	0.0
F						6.7	35.0	5.0	0.0	1.7	36.7	1.7	0.0	1.7	1.7	10.0	0.0	0.0	3.3	0.0	46.7
G							16.7	1.7	0.0	5.0	31.7	3.3	0.0	1.7	0.0	36.7	0.0	0.0	1.7	0.0	43.3
H								0.0	0.0	1.7	1.7	1.7	0.0	0.0	0.0	3.3	0.0	0.0	21.7	5.0	1.7
I									15.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	25.0	0.0	1.7	0.0
J										3.3	1.7	10.0	0.0	3.3	0.0	1.7	0.0	0.0	0.0	0.0	1.7
K											8.3	1.7	0.0	1.7	5.0	6.7	0.0	0.0	0.0	1.7	60.0
L												11.7	0.0	6.7	0.0	3.3	0.0	0.0	0.0	0.0	3.3
M													23.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N														13.3	0.0	0.0	0.0	0.0	0.0	0.0	1.7
O															18.3	0.0	0.0	6.7	0.0	0.0	0.0
P																21.7	0.0	0.0	3.3	1.7	28.3
Q																	5.0	0.0	0.0	0.0	0.0
R																		3.3	0.0	0.0	0.0
S																			11.7	23.3	5.0
T																				1.7	1.7
U																					10.0

Discussion

It would have been desirable if the set of highly discriminable linear symbols identified had contained more than seven lines. In previous research of this type, as here, self-errors have been responsible for diminishing the number of otherwise usable symbols The possibility of subjects acquiring a set for saying different has been considered as there are more unlike pairs than like ones, the proportion being inversely related to the number of symbols being tested. In the set of 21 linear symbols tested here the probability of any one pair being alike was 1 in 11. Although subjects sometimes appeared to acquire a set, overall evaluation of the data does not support this as a general conclusion. In the set tested in the research reported here, the ordinal position of the alike pairs of the seven discriminable symbols were 14, 22, 74, 111, 166, 184, and 231. Obviously they were distributed throughout the entire set The ordinal positions of the alike pairs of the six symbols meeting all criteria except for self-recognitions were 123, 164, 175, 195, 221, and 229. Although these all occur in the last half of the set, so do three of the discriminable ones which makes it appear unlikely that the errors were due to set or fatigue, but rather that certain characteristics of the similar pairs correctly identified make them more easily recognizable than those incorrectly identified

Inspection of the data revealed a possible clue to the self-errors. For the seven highly discriminable symbols, all grade levels made approximately the same number of errors [4-6 (5), 7-9 (6) and, 10-12 (3)] while the lowest grade level made nearly twice as many errors as the higher two levels on the six pairs of like symbols that were discriminable except for self-errors [4-6 (27), 7-9 (14), 10-12 (17)]. Although a grade level difference does appear here, it must be noted that all levels exhibited a greater than 10% error rate on these combinations. To pursue the possibility of a grade level difference further, a second Kruskal-Wallis one-way analysis of variance was run to test for it with a combined set of 13 symbols (A, B, C, H, J, K, L, M, N, P, Q, R, and T). After having been corrected for ties, $\underline{H}$ was found to be 4 72, a value below that required for significance at the .05 level. Therefore, it does not appear that grade level was responsible for the discrimination errors.

Once again the possibility arises that the number of tactually discriminable stimuli (in this case lines) is limited.

The findings of this study have been implemented in map production of the American Printing House.

Summary

Seven symbols from a set of 21 linear symbols embossed in paper were found to meet stringent criteria for discriminability. No significant differences were found in ability to tactually identify these seven symbols between subjects at different chronological ages or at different grade levels. Subjects in the study were 60 legally blind readers of braille enrolled in grades 4 through 12.

CHAPTER SEVEN

COMBINING THREE TYPES OF PLASTIC SYMBOLS FOR MAXIMUM LEGIBILITY

Once legible symbols of the point, linear, and areal types are identified, the problem arises of how they best may be combined to achieve maximum legibility The only previous research on this problem is that of Schiff (1966) who studied the legibility of bar graphs when bars were varied among two degrees of difficulty and several modes of presentation Schiff s findings indicated that where size differences among bars were varied among two degrees of difficulty and several modes of presentation. Schiff s findings indicated that where size differences among bars were small, highly redundant modes of presentation produced fewer errors Where size differences were medium or large, less redundant modes of presentation were equally legible

No such study of combination of symbols in maps has been made. Here the problem differs from that studied by Schiff, in that once the map designer has adapted a scale, the relative size of some symbols (areal and linear) are beyond his control. Size of point symbols, of course, can be set arbitrarily within the limits of legibility.

The purpose of this study was to compare blind students' behavior on three map reading tasks when the symbols employed were presented using two degrees of separation and three modes of redundancy induced by varying relative symbol height.

Method

Subjects

One hundred twenty-six braille readers, equally divided into three groups composed of grade levels 4-6, 7-9, and 10-12, participated in the study Fifty-four subjects were students in public school programs in Cleveland, Columbus, and Parma, Ohio; and Atalanta, Georgia. The remainder were enrolled in residential schools for the blind in Florida, Kentucky, and Ohio. Students within each grade level were randomly assigned to six groups, each composed of four residential and three public school students

Experimental Materials

A pseudomap was the primary experimental material To make this map, a 15 inch square of paper was first marked off in three inch squares Diagonal lines were then drawn in both directions through all the intercepts on the squared page. The lines bounding each square and its diagonals were numbered consecutively from top to bottom of the page in successive columns of squares from left to right These numbers

ranged from 1-90. A table of random numbers was entered and as numbers with last digits falling within this range were encountered, lines bearing these numbers were erased until the number of lines had been reduced to one-half.

Symbols for five lines, five areas, and five points were chosen from among those found highly legible in previous research. These were assigned positions on the map by random means. The random order for assignment of line symbols was modified to provide the long path denoted by the dotted line on the map. The resulting pseudomap is pictured in reduced size in Figure 7-1.

Two master copies of this map, one with symbol separation of .090 inch and the second with separation of .150 inch, were made as follows. The three sets of five symbols involved were reproduced as black images on clear film. Using the original drawing as a pattern, these symbols were cut to correct size and mounted on a sheet of glass with clear plastic tape. Symbol separation in preparation of these masters was determined through use of steel gauges made especially for this purpose. These masters were photographed and this material provided the input for the photoengraving procedure that resulted in the experimental maps used.

As previously mentioned, three sets of maps were made for both symbol separation distances in which the vertical heights of the symbols differed. In type 1, all symbols were of equal height (approximately .018 inch). In type 2, areal symbols were .015 inch and line and point symbols were .025 inch high. In type 3, areal symbols were .015 inch, line symbols .025 inch, and point symbols were .035 inch high. All maps were vacuum formed from styrene plastic .015 inch thick which was draped over a male mold. The molds themselves were photoengravings on Dycril plates. To produce an engraving with images at multiple heights, the highest image was first imposed upon the plate and the surface etched away to attain the desired height disparity. Then the next highest image was imposed on the plate and the process continued.

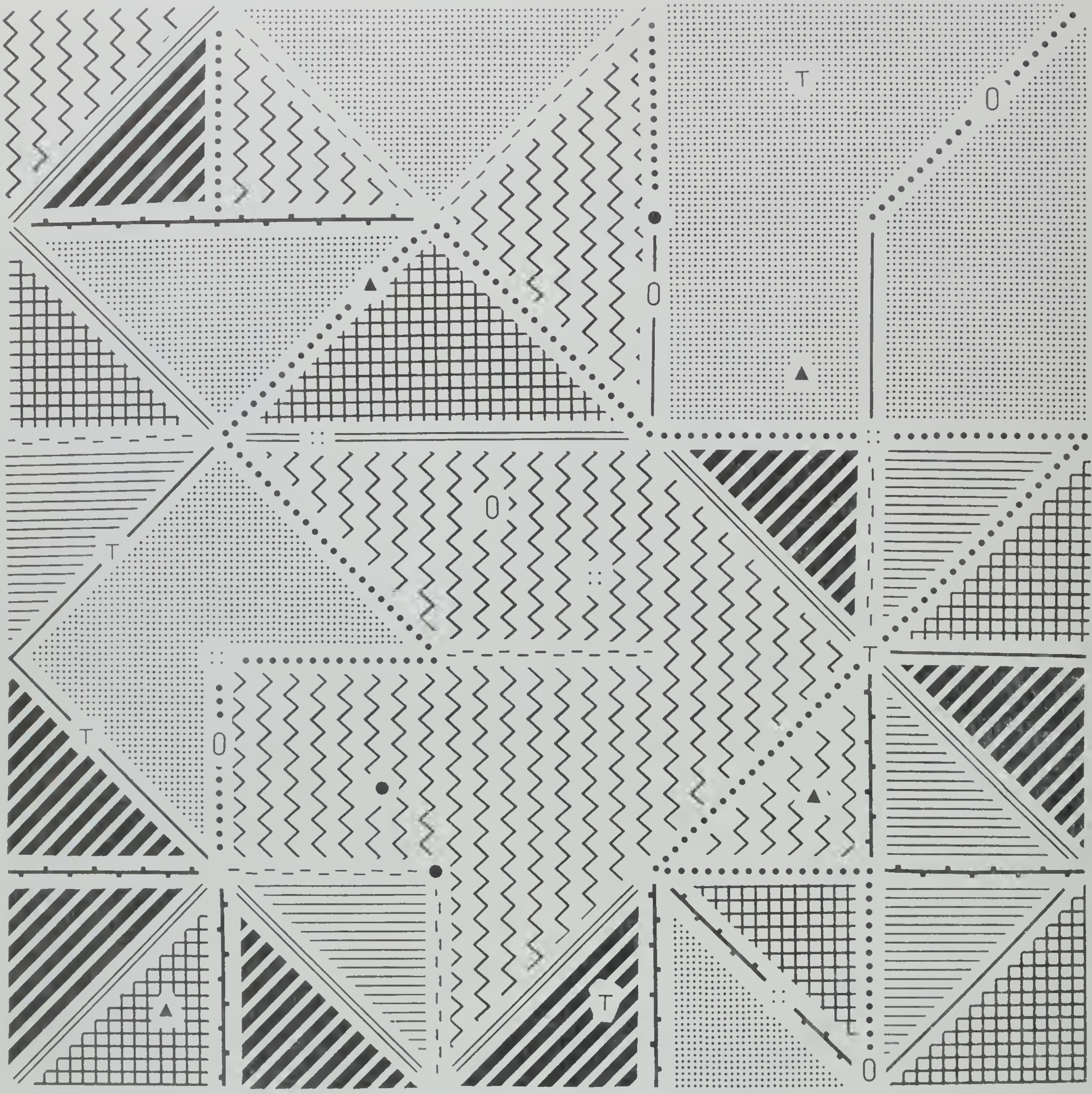

Fig. 7-1. A pseudomap, having wide symbol separation (.150 inch), in which five areal, five linear, and five point symbols have been combined. The map portrayed here has been reduced in size from the ones used in the study by slightly over 50%. The outer dimensions of the pseudomaps used were 15 x 15 inches.

Testing Procedure

Subjects were tested individually by one of two experimenters. Testing sites were in the schools and were generally quiet and secluded.

The task for each subject was to locate the six areas denoted by the symbol composed of squares, to locate the five points denoted by the symbol T, and to follow a path denoted by a dotted line. This path started with the oval point symbol at the bottom of Figure 7-1 and terminated with the oval point symbol in the lower left corner of the map.

Prior to attempting these tasks, each subject was allowed a brief period to inspect the map and explore its dimensions. Following this, he was started on the experimental tasks in the above order. The experimental instructions were couched in terms of exploring "Mr. Brown's farm" (see Appendix A). For all tasks, a reference card displaying the symbol involved was presented prior to the task in order for the subject to gain familiarity with the symbol. The subject could refer to the key at any time during the task. The time required for completion of each task was measured by use of a stop watch and any errors made by the subject noted on a print copy of the map. Maximum time allowed for each task was 10 minutes.

Results

The original design called for analysis of both time and error scores within the context of a 2 X 3 X 3 design Factors varied within the design included symbol separation (.090 and .150 inches), relative symbol height (all top surfaces equal, two levels, and three levels) and grade level (4-6, 7-9, and 10-12). In the analysis of results, error scores have been omitted for areas and lines because of the scarcity of errors for identification of areas and the unreliability of recording errors for lines.

Table 7-1 gives the means and standard deviations for the time scores necessary to identify the areas correctly. Table 7-2 gives the results of analysis of the variance among these means. Relative symbol height was not a significant factor in the time required to locate areal symbols. Distance between symbols also failed to show up as a significant factor Grade level differences and all interactions failed to reach significant levels

TABLE 7-1

Areal Symbols: Means and Standard Deviations for

Recognition Times in Seconds (N=126)

		Space between Symbols					
		.090"			.150"		
Number of Heights-Type		1	2	3	1	2	3
Grade Levels							
4-6	Mean	289	235	305	219	236	327
	SD	169	188	186	174	148	193
7-9	Mean	358	341	290	326	236	291
	SD	192	233	139	197	183	214
10-12	Mean	304	217	266	273	136	87
	SD	157	187	189	205	87	22

TABLE 7-2

Effects of Separation of Symbols by Height and Distance on Time for Identification of Areal Symbols

Source of Variance	df	MS	F
Height (H)	2	46,028	N.S.
Distance (D)	1	98,225	N.S.
Grade Level (GL)	2	100,306	N.S.
H X D	2	262	N.S.
H X GL	4	29,009	N.S.
D X GL	2	17,300	N.S.
H X D X GL	4	18,779	N.S.
Within Cells	108	36,448	
Total	125		

Table 7-3 gives the means and standard deviations of the time scores necessary to follow the path denoted by the dotted line. Table 7-4 gives the results of the analysis for difference among these means. Relative heights of the symbols proved to be a significant factor (.05 level of confidence) in time required to follow lines. With the exception of the means for the lower grade level groups using the wide spacing, these times diminished rather consistently with increases in degree of separation of heights of symbols. Distance between symbols was not significant. The grade level factor was significant at the .025 level of confidence. This difference seems to arise from the opposite trend of the means for the lower grade level groups reading wide spacing.

TABLE 7-3

Linear Symbols: Means and Standard Deviations

for Path Following Times in Seconds (N=126)

Number of Heights-Type		Space between Symbols					
		.090"			.150"		
		1	2	3	1	2	3
Grade Levels							
4-6	Mean	315	201	219	109	143	174
	SD	221	172	168	38	103	177
7-9	Mean	355	321	164	347	269	195
	SD	162	166	78	200	210	113
10-12	Mean	268	161	175	153	252	80
	SD	82	95	115	51	208	51

TABLE 7-4

Effects of Separation of Symbols by Height and Distance on Time Required to Follow a Path

Source of Variation	df	MS	F
Height (H)	2	86,391	3.46*
Distance	1	81,524	N.S.
Grade Level (GL)	2	108,539	4.35*
H X D	2	29,687	N.S.
H X GL	4	28,280	N.S.
D X GL	2	24,055	N.S.
H X D X GL	4	24,972	N.S.
Within Cells	108	24,905	
Total	125		

* Significant at beyond .05 level of confidence

The time limits for finding point symbols which were determined through pilot study proved too limited during the actual experiment. The resulting time score distributions were severely skewed and consequently parametric statistics could not be used to analyze the outcome. Table 7-5 gives the group medians and ranges of the time scores for locating point symbols. As can be seen many individuals took the full amount of time allotted. Of these, 73 out of 126 subjects failed to complete the task by finding all the symbols.

TABLE 7-5

Point Symbols: Medians and Ranges for Recognition Times

		Space between Symbols					
		090"			150"		
Number of Heights-Type		1	2	3	1	2	3
Grade Levels							
4-6	Median	600	600	600	600	600	511
	Range	0	0	311-600	411-600	274-600	44-600
7-9	Median	600	600	515	600	600	251
	Range	0	0	219-600	427-600	340-600	114-600
10-12	Median	600	600	503	600	600	150
	Range	0	410-600	503-600	358-600	392-600	64-600

In order to analyze the effects of the height and distance factors, a count was made of the number of individuals correctly locating all five point symbols under each condition of the experiment and a frequency distribution was made for the number of correct symbol identifications under each experimental condition.

Table 7-6 reports the number of subjects locating all point symbols for each experimental combination and the totals for the space and height variables. Twelve subjects found all symbols under conditions of narrow spacing as compared to 30 successful completions for wide spacing. A chi square test of the possibility for the chance occurrence of relative frequencies of this size yielded a coefficient of 10.21 which was significant at less than the .001 level of confidence. Therefore, the wider spacing resulted in significantly more subjects locating all the points.

Inspection of the height totals in Table 7-6 reveals that five subjects located all symbols with one relative height, 10 subjects with two, and 27 subjects with three. The chi square resulting from the test of these frequencies was 28.48 which was significant beyond the .001 level. This indicated the superiority of the mode employing three relative heights of symbols.

TABLE 7-6

Number of Subjects Locating All Point Symbols

Number of Heights-Type	Space between Symbols .090" 1	2	3	(Totals)	.150" 1	2	3	(Totals)	Grade Totals
Grades 4-6	0	0	2	(2)	2	3	5	(10)	12
Grades 7-9	0	0	4	(4)	1	2	6	(9)	13
Grades 10-12	0	2	4	(6)	2	3	6	(11)	17
Space Totals	0	2	10	(12)	5	8	17	(30)	
Height Totals	5	10	27						

A frequency distribution of the numbers of correct symbol identifications under the two spacing conditions appears in Table 7-7. These distributions do not appear congruent and that for the .150 spacing appears to indicate a higher quality of performance. The test of whether two such differing distributions are the result of chance yields a chi square of 18.26, significant beyond the .01 level. Therefore the wider spacing yields superior performance.

TABLE 7-7

Frequency of Correct Symbol Identifications for the Two Symbol Spacings

No. Correct	.090 Space	.150 Space
0	12	2
1	7	3
2	11	9
3	6	9
4	15	10
5	12	30

Table 7-8 gives the distributions for the number of correct symbol identifications for the three relative symbol heights. Visual inspection of the table indicates that performance is superior when symbols appear at three relative heights. This is confirmed by chi squares significant beyond the .02 level for comparison of all three distributions (52.49), comparisons of distributions for 3 and 2 (19.18), and comparison of distributions 1 and 2 (14.68).

TABLE 7-8

Frequency of Correct Symbol Identifications for

the Three Relative Symbol Heights

No Correct	Number of Heights		
	1	2	3
0	10	3	1
1	8	1	1
2	8	11	1
3	7	6	2
4	4	11	10
5	5	10	27

Results of the study indicate that relative symbol height and symbol distance, as defined within the design, have no effect on recognition of areal symbols by blind elementary and high school subjects. Relative symbol height, but not symbol separation, influenced path following behavior with required time being negatively related to increase in degrees of height differentiation among the three classes of symbols on the map. Both relative height and degree of symbol separations influenced speed and accuracy in location of point symbols with the greatest degree of height differentiation and symbol distance yielding the best results.

These findings tend to confirm some of the principles of tactual perception applying to tactual drawings described by Schiff (1966) and listed in chapter two. Height of tactual edges appeared to contribute to discrimination of lines and points. Enhancement of contrast along the dimensions of form, distance, and level also appeared to contribute. This effect appeared related; however, to the dimensions of the symbology employed. Little or no effect was demonstrated for the larger areal symbols where form alone appeared the dominant cue. Maximum effect on both speed and accuracy of response was shown for the smallest class, point symbols.

Summary

Methods for combining symbols in map form were investigated. Sets of the three symbols were combined in six pseudomaps that varied along two dimensions--horizontal distance between symbols and vertical distance between symbols. Horizontal distance between symbols was varied through two dimensions--.090 and .150 inches. Vertical distance was varied through three conditions. In the first, the top surface of all symbols was the same distance above the background. For the second, the top surfaces of point and line symbols were higher than of that for areas. In the third, the top surface for point symbols exceeded that for lines which exceeded that for areas.

One hundred twenty-six braille readers in grades 4-12 were required to find areas and points and to follow lines under conditions where time and error records were accumulated. While for identification of areas there were no differences among conditions, identification of points and following of lines were superior under conditions of maximum differentiations among symbol height. Identification of points was superior under conditions of maximum symbol separation.

CHAPTER EIGHT

CINEMATIC STUDY OF TACTUAL MAP READING BEHAVIOR

The pilot studies of ways of combining symbols called for random groups of students at the elementary and secondary school levels to attempt several map reading tasks on "pseudomaps" that varied along two dimensions--symbol distance and relative symbol height. In the course of testing the initial forms of the "pseudomaps" the gross inefficiency and inadequacy of the exploratory behavior of the blind subjects was noted. Conversations with these blind children revealed little or no formal orientation or training in the exploration or reading of two dimensional tactile fields.

Examination of the literature revealed only limited and peripheral studies of this problem (Merry & Merry, 1933; Schiff & Isikow, 1966). No studies of tactile tracking behavior were uncovered. Studies in this area would appear to have considerable implication for understanding tactual perception, particularly from the standpoint of developing techniques to teach students to read tactual maps and of designing tactual maps.

Consequently, a pilot study in tactual map reading behavior was undertaken. Its purpose was to record the manner in which untrained subjects explore maps and to attempt to analyze these records systematically. Two types of map reading tasks were observed. The first involved location of tactually coded areas and the second involved tracking a tactual path.

Method

Subjects

Nine elementary and nine high school braille readers at the Indiana School for the Blind served as subjects. Subjects were randomly selected from students of grades 4-6 and 9-12 who had visual acuity of light perception or less. Data describing the subjects can be found in Table 8-1.

TABLE 8-1

Descriptive Data for the Subject Groups

Group		CA (Mos.)	IQ	Sex M	Sex F	Preferred Hand R	Preferred Hand L
Elementary	Mean	152.6	101.0	5	4	9	0
	SD	18.1	13.6				
Secondary	Mean	214.0	119.4	5	4	7	2
	SD	19.3	16.8				

The secondary subjects had considerably higher mental ability than did the elementary subjects. These differences did not appear related to the selection procedures but to the fact that the secondary group as a whole was exceptional.

Procedure

One session approximately one-half hour in length was required of each subject. All subjects were examined in the same room over a two day period. The subjects were seen in alphabetical order by grade levels alternating between the upper and lower schools. The area location and path tracking tasks were alternated in order between subjects at each grade level.

The pseudomap used in the study is pictured in Figure 7-1. Subjects worked at each of the map reading tasks for five minutes or less, if the task was completed before that time. The tasks used were identical to the area finding task and path following task described in chapter seven. Instructions for the tasks were the same as those in Appendix A except that no opportunity was given to examine the map prior to attempting the tasks.

During the task time, motion pictures were taken of the subjects' hands as they were employed in the exercise. Black and white pictures were taken from an angle above and in front of the subject. The camera was a Bolex H-8 which had been modified for electrical drive. The speed of the camera during filming was 32 frames per second (fps).

Analysis of Cinematic Records

All motion pictures of the map reading behavior of the subjects were projected for analysis at six fps. This resulted in a projection time of more than five times the filming time or of approximately 26 minutes for subjects requiring the full filming time to complete the task All data are reported in terms of projection times. During quantification of the records, behavior times were recorded to the nearest quarter second using a GraLab Universal Timer, Model 172

One judge quantified all 36 cinematic records Films for each subject by task were projected on a screen space of 24 X 34 inches. The projector used, a Kodak Instamatic M-80, allowed the judge both forward and reverse projection capabilities as well as that of observing still frames

For the path tracking task, time was recorded for traversing each segment of the dotted line between changes in direction of the line and interrupting symbols. Records were also made of the time spent at choice points where line directions changed and where interrupting symbols were present The total task time for each subject was the sum of all these times Inspection of Figure 7-1 will help the reader in understanding the timing technique

Also recorded were "On" and "Off" times for each reader. "On" time was the amount of time spent following path segments in the direction from start to finish. "On" time was time required for the initial tracing in the goal direction and at intersections on the first time through when the individual was searching for the path Time spent at intersections was recorded as "On" when it was obvious that the subject was looking for the continuation of the path by (1) keeping one finger on its terminus while searching for the continuing segment with the other hand and (2) confining this search to within a square area formed by the diagonals of line segments with the intersection at the center. "Off" time was any time not spent as described above as well as time doubling back along the path towards the origin and then retracing towards the goal.

For the area identification task, the films were projected on a 5 x 5 cell gridded screen with the grids drawn to fit the perspective of the pictures of the map. A record was then made of the time each hand of the subject was located in each cell of the grid during the task activity

Results

In Table 8-2 appear several indices of performance for the two map reading tasks for both elementary and secondary groups. For the area identification task the mean number of correct identifications and the mean task time required for the identification of symbols are given. For the path following task an overall performance index is given as well as the number of subjects in each group completing the task. While none

of the differences between grade groupings reached statistical significance, a consistent trend toward better performance by secondary pupils as well as toward reduction of variation within this group suggests that motivation and/or learning play significant roles in development of map reading skills.

TABLE 8-2

Performance on Two Map Reading Tasks

Group		Area Identification		Following Path	
		Number Correct	Time/Symbol Location (Min.)	Performance Index*	Subjects Completing Task
Elementary	Mean	3.3	1.8	39.06	3
	SD	2.0	1.4	41.68	
Secondary	Mean	5.1	1.1	21.20	5
	SD	1.6	1.4	24.26	

* This index is based on the ratio of the total time spent not directly proceeding along the path to the goal to the total time spent proceeding directly along the path to the goal when this latter measure is expressed as a percentage of total time spent on the task.

Correlations between map reading performance, IQ, and several measures of academic achievement appear in Table 8-3. These latter scores are derived from the Stanford Achievement Test at the elementary level and the Sequential Tests of Educational Progress at the secondary level. For elementary students, the only significant correlation is between the two map reading indices. At the high school level, significant relationships are found between performance on both tasks and measures of IQ, reading comprehension, and arithmetic computation. For this group, the two map performance measures are much more closely related.

TABLE 8-3

Correlations between Map Reading Scores and Academic Variables

		Academic Achievement Test				
	IQ	Paragraph Meaning	Word Meaning	Arithmetic Reasoning	Arithmetic Computation	Area Identification
lementary						
ime/Symbol Located	-.50	-.20	-.09	.11	.25	
ath Performance Index	-.54	-.20	.08	.20	.10	.68*
econdary						
ime/Symbol Located	.85**	.80**	.50	.44	.88**	
ath Performance Index	.80**	.67*	.61	.43	.78**	.93**

* p .05 = .65

** p .01 = .76

The next four tables concern various aspects of performance on the area identification task. The first, Table 8-4, indicates the proportion of each group who demonstrated several search techniques that logically would appear to make performance not only more efficient but more meaningful. That these techniques are quite simple is demonstrated by the first which would consist of running the hands around the edges of the map in order to define the extent of the field to be searched. No student in either group did this, but instead immediately embarked on a detailed search of the field. The second technique would involve an attempt to get a general idea of what the map surface was like in order to attain some overall frame of reference within which to organize the search. This might be accomplished by brushing the hands in a gross way rapidly over the entire map surface. No participant did this. The third technique would use both hands simultaneously in a coordinated manner. Every subject appeared to do this. The last technique would employ some systematic pattern of search as by rows or by columns in sequence or use

of a diminishing rectangular pattern. No elementary student used a systematic procedure. One-third of the secondary students used systematic search patterns usually by rows or a combination of rows with columns.

TABLE 8-4

Proportions of Subjects Demonstrating Efficient Area Search Techniques

Technique	Group	
	Elementary	Secondary
1. Defines extent of field	.00	.00
2. Attempt overall frame of reference	.00	.00
3. Coordinated use of both hands	1.00	1.00
4. Systematic search pattern	.00	.33

The effects of lack of use of systematic search patterns are illustrated by the data presented in Table 8-5. These data represent the proportion of total time spent searching each row or column when the map was evenly divided into a 5 x 5 grid. For both groups, greater time was spent searching the inner rows and columns and less time spent searching the rows and columns representing the edges of the map. The effects appear most pronounced at the elementary level.

TABLE 8-5

Proportion of Search Time Spent in Map Areas in Area Identification

Section Number	Elementary		Secondary	
	Rows*	Columns**	Rows*	Columns**
1	.10	.15	.16	.16
2	.20	.24	.23	.19
3	.26	.25	.22	.23
4	.26	.23	.20	.23
5	.18	.13	.20	.19

* Top to bottom
** Left to right

Table 8-6 shows that left and right hands were used individually to explore the map but in about 50% of the cases this was accomplished through coordinated use of both hands. The grade groups were quite similar in this; however, individual left hand use appeared slightly more pronounced in the elementary group. The secondary group appeared superior to the elementary in terms of average time to complete the task and, in addition, in terms of rate of search or cells searched per minute.

TABLE 8-6

Mean Number of Cells Explored with Each Hand and Related Time

	Hands			Mean Task Time (Min.)	Cells Searched/Minute
	Right	Left	Both		
Elementary	92.6	87.3	179.9	4.32	41.6
Secondary	92.7	79.6	172.3	3.67	46.9

Similar data couched in terms of successful area identifications appear in Table 8-7. Elementary and secondary groups appear similar in the extent to which symbols were located through independent use of the left and right hands. However, the secondary group appears to exceed the elementary in use of both hands for this purpose.

TABLE 8-7

Number of Correct Area Identifications with Respective Hands

	Hands			
	Right	Left	Both	Total
Elementary	12	5	13	30
Secondary	13	8	25	46

The last two tables describe performance on the path following task. Table 8-8 contains data relative to efficient tracking behavior. The first item indicates the proportion of the subject groups who seemed to have an initial concept of tracking or path following behavior. Less than half of each group fell in this category. Others appeared to develop the idea in the course of the experimental period. Use of both hands is critical in tracking an interrupted path. Two-thirds or more of both groups used both hands. Use of two hands was critical because when the path was interrupted it was necessary to hold place with one hand while searching for the path with the other. Elementary students using both hands did this; however, such was not the case for all secondary subjects. Where choice points occurred systematic search for the continuation of the path was critical. Two-thirds of elementary subjects were systematic while less than half of the secondary subjects could be so described. These latter two items were the only indices for which elementary subjects were superior.

TABLE 8-8

Proportions of Subjects Demonstrating Efficient Path Following Techniques

Technique	Group	
	Elementary	Secondary
1. Appears to have concept of path	.44	.44
2. Uses two hands	.67	.78
3. Holds place while searching	.67	.56
4. Systematic search at choice point	.67	.44

The last (Table 8-9) gives the mean performance times for the path following task. <u>"On" time</u> is the time spent tracking the path toward the goal. <u>"Off" time</u> is the time spent tracking in a reverse direction, tracking on the wrong symbol, and searching at choice points. As data in the table indicate, secondary subjects were superior to elementary subjects on all indices of path following performance.

TABLE 8-9

Mean Times (Sec.) for Path Following Task

	On-Time	Off-time	Total	Performance Index*
Elementary				
Mean	383.06	756.86	1139.92	39.06
Range	209-848	151-1263	473-1504	2.23-112.05
Secondary				
Mean	367.67	423.03	901.75	21.20
Range	220-579	0-1126	220-1468	.01-67.6

* These indexes are averages of individual subject ratios and cannot be computed from the mean on-and off-time figures.

When queried on map reading training, 55% of both groups reported no formal training and little experience. The remainder reported little training and little actual experience.

Discussion

The extent of the lack of formal training and experience by these small groups of blind students was impressive. Informal observations by the authors in other schools indicate that this situation is the rule, not an exception. Lack of formal training is reflected in the inefficient procedures used by the students.

The developmental picture portrayed in this study is reminiscent of that found for braille reading (Nolan & Kederis, 1969, pp. 43-44). At the elementary level, basic development in the area of tactile discrimination is still not complete. Only after these basic abilities have been developed, can intellectual factors come into play. At the high school level, such development is complete and perceptual models for map reading and related activities can be developed. This shift in level offunctioning explains the lack of correlation between this activity and IQ at the elementary levels and the subsequent appearance of a considerable positive relationship during the high school years.

The poor techniques displayed by the readers reflect the lack of training cited above That similar training deficits exist for the blind in use of recorded texts has been mentioned by Morris and Nolan (1969). While the validity of the techniques mentioned in this paper and the degree to which they facilitate map reading are at this time speculative, these can be empirically verified and research for this purpose should be carried out.

Summary

Motion picture records were made of nine elementary and nine secondary students who read a tactual map. All students were braille readers. All students were required to tactually locate coded areas and to follow a tactual path. Analysis of the results revealed no grade differences in ability to complete the tasks, that most students had little formal training and restricted experience in map reading, that in many instances inefficient procedures were used, and that the developmental pattern for map reading bears many resemblances to that for braille reading.

CHAPTER NINE

THE PROBLEM OF MAP READING TRAINING

The final proposed goal for this project was the development of a pilot training program for more adequate map reading behavior. Preliminary attempts to develop this program ran afoul of the vicious circle of problems that besets the teaching of the geographical aspects of social studies curricula. It might be well to start the description of this circle at the point which stimulated the project described in this report.

Maps for the blind lack legibility and are difficult to read. Principal reasons for this are lack of basic knowledge of tactual perception leading to consequent problems of map design and legible symbology. Because of the poor quality of maps, teachers do not employ them widely in instruction. Therefore, blind students gain little experience in map use. Lack of use by teachers and students has resulted in little attempt to identify and teach systems for tactual map reading. In addition, avoidance of maps and its accompanying reduced stress on geographical material has led to the situation where blind children lack basic geographical concepts and information. Consequently, attempts to test new map innovations and designs are frustrated by lack of geographical knowledge and map reading skills on the part of blind students who must be the subjects in experiments to test tactual map designs.

Evidence exists within the literature to support this conception of the problem. Lack of information concerning tactual perception is discussed in chapters one and two of this report and is more specifically discussed by Nolan (1969). The lack of training and experience in map reading is implied by the data reported in chapter eight. Problems in achievement in the area of geography were originally raised by Hayes (1937) and recently confirmed by Franks and Nolan (1970). Lack of skill in map reading techniques is indicated by the findings of the study described in chapter seven.

Analysis of the map problem in the above manner suggests that research on map training will not be fruitful and that the best place to break the circle is at the conceptual level. Once concepts of orientation and geographic features of the earth are learned, the student can be taught map reading techniques and maps can be tested. It was for these reasons that the pilot training goal was not pursued.

Subsequent to the termination of the project described in the report, research on the conceptual area has been conducted. This work was carried out in the Instructional Materials Reference Center of the American Printing House by Franks and his collaborators (American Printing House, 1970, p. 9). The result was the development of a unit to teach general concepts of physical orientation and concepts of 40 physical features of the earth commonly depicted on maps. This latter instruction utilizes seven small pseudomaps or landforms as instructional aids. Accompanying the program are especially developed proficiency measures. All materials have been evaluated and refined in use with blind students over a wide range of grade levels.

CHAPTER TEN

CONCLUSIONS AND SUGGESTIONS FOR RESEARCH

The purpose of this final chapter is to attempt to integrate available information in ways that can contribute to our ability to design and use tactual maps. Unfortunately, such information is sparse. The bibliography of this report contains only 24 directly relevant citations. Consequently, an additional purpose will be to attempt to identify areas of needed research and development. The major topics to be covered will be factors in symbol legibility, factors in map design, and development of map reading techniques.

Factors in Symbol Legibility

Symbol Separation

As reported in chapter two, the two-point limen for touch at the fingertip has been found to be .090 inch for static touch with reduction in this value with active touch. Since this index is a mean value for the population measured, it can be expected that about half would be unable to discriminate points this close. Consequently, symbol separation should exceed .090 by some unspecified amount to enable most tactual readers to make the necessary discrimination. In chapter seven it was found that increase in symbol separation from .090 inch to .150 inch failed to result in improved discrimination for areal and linear symbols but did improve discrimination for point symbols. Subsequent research by Bentzen (1970, p. 34), implies that, at least for adults who are of average ability, separation of .125 inch may be significant. A general rule for symbol separation seems to be that it should never be less than .090 for bulky symbolic representation and that symbol separation should be increased as symbols become smaller approaching the .150 inch distance when point symbols are employed.

Symbol Characteristics

Areal symbols. Research by Morris and Nolan (1961) as well as that reported in chapter three indicates that at least three stimulus features contribute to discriminability of areal patterns. These include whether patterns are composed of continuous as opposed to interrupted parts, whether patterns are regular or irregular, and the size of figures making up a pattern. An additional stimulus feature reported by Schiff (1966) includes the intensity or sharpness of the tactual stimulation. Features not contributing to legibility include the shape of the textural elements making up an areal pattern (Schiff, 1966) and the directional orientation of elements within a pattern (chapter two; Pick, Klein, & Pick, 1966; Schiff, 1966). However, it was felt this latter feature might become meaningful with training.

Linear symbols. Dimensions which seem to differentiate linear symbols are reported by Nolan and Morris (1963) to be continuous-interrupted, thick-thin, smooth edged-ragged edged, and single-double. These authors and Schiff, Kaufer, and Mosak (1966) suggest that rhythm of stimulation may also be a factor. Schiff (1966) found differential intensity of stimulation according to the direction of scanning a useful feature in indicating directionality in linear symbols.

Point symbols. Features reported by Nolan and Morris (1963) as contributing to discriminability of point symbols include form, size, solid-outline, and continuous or punctate. Corners of small figures appear to play a significant role in legibility. For punctate figures, discriminability falls off if interdot distances fall below .090 inch (Nolan & Kederis, 1969). These authors found number of dots in a figure negatively related to legibility. Complexity is also a factor with legibility diminishing markedly when matrices within which such figures may occur exceed a 4 x 4 array (Foulke & Warm, 1967).

Size Effects for Symbols

Areal symbols. These symbols begin to diminish in legibility when area drops below one and one-half inches square (Nolan & Morris, 1963). Overall legibility remains good until symbols are reduced to from three-quarter inch squares (Nolan & Morris, 1963) to one-half inch squares (Heath, 1958). Interrupted-regular patterns (formed of small dots or thin parallel lines) tend to retain legibility when reduced to small size.

Line symbols. No data exist concerning minimum lengths for line segments. One-half to one inch lengths appear minimum depending on the pattern of the symbol. Simple continuous symbols would probably be legible near one-half inch. As patterns for symbols increase in complexity and in size of the elements of which they are composed, longer minimum lengths would be required to retain legibility.

Point symbols. Chapter three indicates that point figures composed principally of solid and outline forms are legible with diameters of .20 inch, but that legibility falls off when diameters are reduced to .15 inch on a side. This suggests that the larger size may be nearer optimum. For punctate figures symbol legibility diminishes when interdot separations are less than .090 inch (Meyers, Ethington, & Ashcroft, 1958). Legibility also diminshes when a punctate figure increases in interdot distance although the specifics of this shift are not yet clear.

Limitations on Numbers of Legible Symbols

A frequent plea among those concerned with use of tactual maps is for standardization of use of symbols. Such practice is quite common for maps for the sighted and is made possible by the large numbers of printed forms which can be put to symbolic use. Research findings on tactual symbols imply that the number of available discrete symbols in all categories may be so few as to preclude even rudimentary standardization.

Research by the authors of this report is the primary source of data on symbol number limitation. For areal symbols the results are as follows: Morris and Nolan (1963) 12 symbols were compared and eight found discriminable, Nolan and Morris (1963) 13 symbols studied yielded seven that were discriminable, and in chapter three, 11 symbols were studied and eight proved discriminable. For line symbols the results were: Nolan and Morris (1963) 18 symbols were compared and four were found discriminable, 12 linear symbols were compared and five found discriminable; 13 linear symbols were compared and seven found discriminable, in chapter three, 13 symbols were studied and seven found discriminable, and in chapter six study of 21 symbols revealed seven to be discriminable. For point symbols the findings were: Study of 18 symbols by Nolan and Morris (1963) resulted in identification of one legible symbol, analysis of 12 symbols revealed three to be discriminable, study of a set of 14 symbols showed eight to be discriminable, in chapter four eight of 12 point symbols were legible, and in chapter five study of 19 symbols embossed in paper indicated that eleven were discriminable. A report by Wiedel and Groves (1969, p. 8) suggests that they have found a set of four lines discriminable among 17 studied and three points discriminable among 15 studied. Thus, in no instance where various sets of forms have been compared for discriminability, have more than 11 met legibility criteria. This is in marked contrast to braille which has 63 discriminable forms within a six dot matrix.

Symbol Research Needed

Further investigation and identification of the parameters that contribute to discriminability of symbols within the three classes is needed. Design of sets of symbols through systematic variation of combinations of these parameters should be attempted. Further exploration of the use of English alphabet upper case letters as point symbols (Schiff, 1966) seems desirable. Use of the Boston Line Letters for this purpose should be explored particularly.

Factors in Map Design

The problem of tactual map design is complicated by lack of knowledge of the specifics of tactual perception and of adequate map reading techniques. Critical problem areas are those of size, legibility, and symbol standardization.

Map Size

In practice the size of tactual maps varies from the 11 x 11 inch page found in braille books to the 42 x 50 inch dissectable easel type maps made of molded rubber. In the past the size of maps appears to have been dictated by such things as restrictions imposed by the media (i.e., book size), the area to be depicted, the amount of information to be displayed, and the complexity of the display. The problem of map size is inextricably bound up with those of map legibility which will be discussed next. No formal studies of this problem are reported in the literature. Wiedel and Groves (1969, p. 50) conclude that map size should be kept as small as possible but advance no basis for size decisions. Formal study of the problem of map size in conjunction with those of map legibility is a critical need if progress in map design can occur.

Map Legibility

The legibility of a tactual map might be simply defined as the extent to which each feature represented on the map stands out as a clear figure against a background and the extent to which each feature can be related meaningfully to all other features displayed on the map. Variables affecting legibility include the amount of information to be displayed, the complexity of this information, figural-quality of symbology, the redundancy of these figures, the availability of reference points, and others. It goes without saying that these variables are highly interrelated among themselves and play a decisive part in determination of map size.

Amount of information. It is desirable, particularly in educational settings, that blind children have access to the same maps in their textbooks and elsewhere as do sighted children. Attainment of this goal is made difficult because of the following paradox. In comparison to that for vision, the perceptual span for touch is extremely limited making the task of reading maps far more difficult and prolonged. Consequently, tactual maps should be as small as possible. In comparison to that for vision, tactual acuity is much more coarse requiring tactual figures to be much larger than visual figures in order to be discriminated. This requires tactual maps to be much larger than visual maps if the same information is to be presented. ?

A common solution to this problem is to present the information contained in a complex visual map to the blind in the form of several small tactual maps. The problem of interrelating this information to achieve that given by the single print map remains. However, Bentzen (1970) has shown that, at least for adults, this can be done by presenting maps in overlay form, where information obtained from one by the left hand can be related to that obtained from the second by the right hand. ?

These difficulties suggest the research problem of finding ways to reduce the size of tactual symbology while at the same time enhancing the clarity of such stimuli.

Complexity. This factor is dependent on the density of the stimulus field which in turn is dependent on such things as symbol size, symbol separation, and the amount of information to be displayed. As complexity of tactual graphics increases, legibility tends to decrease as it becomes increasingly difficult to distinguish individual figures from other figures or from their mutual background. This of course is the classic signal/noise problem of communications system.

Authors call for simplicity in map design (Wiedel & Groves, 1969) to solve this problem. One way to achieve simplicity is through the multi-presentation approach previously described. Basically, however, the conditions for optimum simplicity or minimal complexity in tactual graphics have never been defined. Such definition comprises an additional research problem of some magnitude.

Figure-ground. The conditions that determine the figural quality of tactual representations have yet to be explored. Almost no research literature exists. The research on tactual symbols as well as general experience emphasize that indices of visual figural quality have limited validity for predicting tactual figural quality. Even commonly accepted practices of long standing in presenting tactual figures are questionable. In recent research by Nolan (1971), the considerable differences in legibility between figures incised in a surface and those raised above a surface were demonstrated. Less legible incised figures have long been used in maps and diagrams. A critical research gap lies in the figures-ground area.

Figural-redundancy. One aspect of the figure-ground problem that has been explored is the effects of redundancy on figural quality and the legibility of graphics. This work is described in Schiff and Isikow (1966) and in chapter seven of this report. Simply stated, these findings emphasize the importance of making tactual figures different along as many dimensions as possible. Increasing the redundancy of tactual figures tends to compensate for increased complexity in graphic presentations. Future research should explore not only the ways in which redundancy of tactual figures can be increased but also how such increases affect legibility of complex tactual displays.

Symbol Standardization

The restrictions imposed on standardization of meaning for symbols by the relatively small numbers of legible symbols in each class have already been pointed out. Prospects for increasing these numbers are not bright. Some hope lies in the exploration of the usefulness of print upper case characters for point symbols and study of the use of training for making symbol orientation a cue in the case of areal and point symbols. However, until an inventory of greater numbers of legible symbols is accumulated, the potential for standardization is limited.

Reference Points

The provision of adequate reference points for maintenance of proper orientation in tactual map reading has largely been ignored. In print maps, these are provided by directional indicators and grid systems. Wiedel and Groves (1969) point out the inadequacy of the print compass-rose when reduced to tactual form and suggest indicating north by coding the entire appropriate edge of the map. The problem of coordinate frames of reference has not been empirically explored. When attempts to include coordinate systems on tactual maps have been made the results have been disappointing. Provision of tactual grid lines has resulted in these becoming figures rather than ground with resulting loss of legibility and confusion. For example, on tactual graphs it is frequently impossible to distinguish the data curves from the grids in the graph paper. Consequently, the problem of provision of appropriate reference points is of high research priority

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Map Reading Techniques and Training

The development of adequate map reading techniques is dependent upon sequential growth of the child in a number of interdependent areas over a span of several years. The early stages of growth are congruent with the readiness stages for reading and arithmetic and become more specific to map reading as growth progresses. These stages and some of their research and development implications will be sketched below.

General Readiness

This, of course, involves general development in the motor and verbal conceptual areas. Of particular importance to reading graphics are motor coordination required for tactual examination of displays and conceptual development of such things as geometrical form, texture, and spatial relations. Even more specifically the child must attain concepts of the common features of the environment and his everyday world as they relate to a growing concept of himself. Educational methods and materials for this purpose need development. Examples of these are described by the American Printing House (1970, pp. 5-13).

Attainment of the Map Concept

Once the child has achieved some realistic concept of his environment, he needs to attain the idea that this environment can be represented abstractly in the form of a map. An appropriate part of the environment for initial representation in abstract form might be the child's own classroom. From this point, abstract representation of the school, in whole or part, and the school grounds might follow. Simple methods and materials to enable classroom teachers to accomplish these goals require development.

Learning Geographical Features of the Earth

As the child goes through the grades, he should learn the features of the earth as they appear in various parts of the curricula. Current research shows this goal is not met (Franks & Nolan, 1970). At the same time materials should be available to show how such geographical features can be depicted on maps. Materials illustrating 40 such features have recently been developed, (American Printing House, 1970, pp. 8-9); however, additional materials are needed.

Characteristics of Maps

The learning of geographical features of the earth should be accompanied by instruction in the concept of maps per se. Methodology and sets of accompanying materials of increasing levels of difficulty should be developed to teach students the characteristics of maps and the kinds of information that can be conveyed through these means.

Inspection Techniques

The answer to the question of what is the most efficient way to read tactual graphics at this moment is not clear. The importance of achieving a general frame of reference prior to detailed inspection needs study with respect to both gaining an idea of the overall extent of the graphic and its gross characteristics. ~~The~~ ability of varying patterns of search in order to find specific points on a map has yet to be explored. Many maps and other graphics require tactual tracking or path following about which little is known. Tactual area estimation is an unknown quality. The validity with which shapes of areas can be portrayed with outline presentations, particularly as these vary in size, is unknown. How effectively relationships between parts of a large display can be established needs study. Distance estimation is another problem.

In conclusion, it should be apparent by now that the problems of tactual maps are many, complex, and highly interdependent. Undoubtedly, the issues of symbol legibility, map design, and map reading techniques are open to study and solution. However, a broad program combining both basic and applied research will be required to attain this end.

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APPENDIX A

INSTRUCTIONS--TACTUAL SYMBOLS

Before you is a map of Mr. Brown's farm. Please do not touch it until I have told you about it. Mr. Brown's farm is divided into many fields, such as wheat fields and corn fields. The fields are separated by roads, fences, and hedges. Located within the farm are many things such as buildings, trees, wells, and ponds. These many things on Mr. Brown's farm are represented on the map by different kinds of patterns, lines, and dots. These are combined in many different ways.

In a moment I am going to ask you to find some of these things on the map. But before we begin you may examine the map for a short time. (Start stopwatch) As you examine it try to compare the different patterns, lines, and dots used as symbols on the map. (After one minute) The best way to use a map is to explore it systematically. It is always good to get an idea of the overall size and shape first. This can be done by locating the outside border of the map and following it all the way around. See if you can do that. (Pause) Next, you will want to learn what the interior is like. One way this can be done is by examining it somewhat like you would read a braille page. Using one hand to mark your place, use the other to "read" the map. Try it. (Pause; elaborate on the instructions if necessary) All right, remove your hands from the map. As you attempt the tasks I will describe, do not put your hands on the map until I say "begin." Remove them when you finish each task or when I tell you to do so.

(1) On Mr. Brown's farm are six apple orchards. These apple orchards are represented by this pattern or symbol. (Present reference symbol to subject) Feel the symbol carefully with both hands and try to get a good idea of how it feels. Do not bother about its overall size or shape, just feel the center part of the symbol. You may refer back to this symbol as often as you like while you are searching the map. When you have finished examing the symbol set it down by the map where it will be convenient for you to use. Now, search the map for the apple orchards represented by this symbol. As you find the apple orchards, tell me and point to each so I will know which orchard you mean. You should also count them aloud so you will know when all six are found. If any of the orchards are counted more than once I will tell you. Do you have any questions? (Pause) All right, "Begin!" (Time search) Maximum time allowed--10 minutes

(2) Mr. Brown likes Christmas very much. He is always sure to have several Christmas trees growing on his farm. The trees are represented by the symbol here. (Present reference symbol to subject) The symbol is in the center of the small square of plastic. Do not bother about how the small square of plastic feels, just the symbol at its center. Use both hands to feel it. You will be able to refer

back to it, as before, but examine it carefully now and try to learn how it feels. (Pause) Now, look for five Christmas trees. As you find them tell me and point to them. Count them as you did the apple orchards. "Begin!" (Time search) Maximum time allowed--10 minutes.

(3) Mr. Brown has several ponds on his farm. Two of them are connected by a path. The ponds and the path are represented by these symbols. (Present reference symbol to subject) The pond is at one end of the symbol for the path. Examine both the path symbol and the pond symbol closely with both hands. Notice how the path changes directions? (Pause) All right, set the reference card down. The path on the map turns and twists in many different directions and is also interrupted sometimes by symbols for other things. When these things happen you must search around until you pick up the interrupted path then continue following it. I will show you the location of one of the ponds. You follow the path leading from it until you reach the second pond. When you have found the second pond, tell me. Do you have any questions? (Pause) All right, here is the first pond. (Place subject's reading finger on the pond symbol) "Begin following the path!" (Time search) Maximum time allowed--10 minutes